Vol. XXII, Part IV December, 1952

THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE

Issued under the authority
of
The Indian Council of Agricultural Research

सत्यमेव जयते

Annual subscription
Rs. 15 or 23*s*. 6*d*.

Price per part
Rs. 4 or 6*s*. 6*d*.

Published by the Manager of Publications, Delhi
Printed by the Government of India Press, Calcutta, India,
1953.

ICAR. 5. XXII. 4.
780.

CONTENTS

VOL. XXII, PART IV

(December, 1952)

The Publications Committee of the Indian Council of Agricultural Research, India, takes no responsibility for the opinions expressed in this Journal

Original articles

Reviews

ORIGINAL ARTICLES

STUDIES ON *SACCHARUM SPONTANEUM* L.

II. MORPHOLOGICAL AND ANATOMICAL VARIATIONS IN SOME SOUTH INDIAN TYPES*

By Ram Chandra Singh, M. Sc., Assoc. I. A. R. I., Agriculture Department, Government of Utter Pradesh and Sunil Kumar Mukherjee, D. Sc., Botany Department, Delhi University

(Received for publication on 7 September 1951)

(With Plates XXIV—XXVIII)

SACCHARUM SPONTANEUM L. (*Kans* or *Kash*), which occurs throughout India under diverse conditions, has contributed towards the parentage of all the hybrid sugarcanes produced at the Coimbatore Station since 1915. It shows interesting morphological [Panje, 1933], ecological [Brandes *et al.* 1939 ; Mukherjee, 1949], and cytological [Parthasarathy and Subba Rao, 1946] variations, as in Sugarcanes [Stubbs, 1897 ; Kruger, 1899 ; Hadi, 1902 ; Deerr, 1911 ; Barber, 1915-19 ; Jeswiet, 1916, 1925 ; Bremer, 1930 ; Dutt and Subba Rao, 1933, etc.]. Due to its importance in sugarcane breeding, an assemblage of the variant forms had been undertaken by the Sugarcane Research Stations throughout the world. Panje [1933] first studied the 13 forms available in the Coimbatore collection, and discussed the taxonomic significance of their morphological and anatomical characters. Artschwager [1942] recently made an exhaustive study of the vegetative characters of 23 clones of *S. spontaneum*, assembled from different parts of the world at the Sugar Plants Investigation Bureau in America.

Previous observations at Coimbatore indicated the prospect of finding out considerable variability in the forms of *S. spontaneum* and allied species in India. A ' Spontaneum Expédition ' was, therefore, financed by the Indian Central Sugarcane Committee to explore, collect and study all the variants of *S. spontaneum* and allied grasses occurring throughout India. The survey of South India, Orissa and Bengal has been completed by Mukherjee [1949], and 125 types of *S. spontaneum* were collected from South India. A detailed morphological and anatomical description of some of the promising types is presented in this paper, as this will be of interest to sugarcane breeders throughout the world. These types include representative collection from different parts of South India. They show distinctive variations from each other and are being maintained as such through clonal propagation. Forms occurring in nature show variation patterns in morphological and anatomical characters, more or less similar to those found in these types.

Materials and methods

Morphological observations have been made from 8-9 months old shoots of clumps, raised from cuttings of original collections and grown under identical

* The work was conducted at the Indian Sugarcane Breeding Station, Coimbatore, under the Indian Agricultural Research Institute, New Delhi.

conditions in the clay soil of the Quarantine Area of the Station. For description of the types, certain standards for different parts have been fixed [Bourne, 1935]. The height of the plant is the length from ground level up to the last transverse mark, the thickness of stem is from the middle portion, and the colour noted from the exposed basal portion of the cane. The characteristics of the leaf sheath, circlet of hair, bud, root zone and growth ring have been studied from the node containing the topmost dry leaf, and those for lamina from the second leaf above the top-most dry leaf, and other organs of the leaf from the third fully unfurled leaf below the top. The length of the internode has been mentioned as ' short ' when less than 10 cm. long, ' medium ' when 10-15 cm., and ' long ' when above 15 cm. The lamina is ' short ' when less than 90 cm. long, ' medium ' when 90-125 cm., and ' long ' when above 125 cm. ; and ' narrow ' when less than 0·7 cm. in width, ' medium ' when 0·8-1·0 cm. and ' broad ' when above 1 cm. wide.

For anatomical studies, sections of stem and leaf stained with safranin and light green, and stem and leaf epidermal peelings, macerated and stained according to Artschwager's method [1930], have been examined. The anatomical data have been recorded from an examination of 10 samples of each type. The samples were collected from mature bottom portion of the stem (10-11 months old) and from the second leaf above the top-most dry leaf. The figures given in Table II are the average mean of 10 random observations from an area of one fifth millimeter square as seen at 400 times magnification under the microscope. The drawings have been made with the help of Spencer's Abbe Camera Lucida.

Morphological characters and their variation

Apart from the qualitative characters, some comparative quantitative data have been recorded as these may be more useful from the economic point of view (Table 1).

TABLE 1.

******Data on tillering and other stem and leaf characters in mature plants (8 to 9 months old)*

Type number	Total number of tillers per clump	Length of buds in mm.	Lamina size		Leaf module
			Length in cm.	Breadth in cm.	
SES 1	23	5·0	79·9	0·9	1 : 89
,, 4A	82	7·0	85·5	1·0	1 : 86
,, 6	110	7·0	114·0	1·2	1 : 95
,, 8	105	7·0	92·2	0·8	1 : 115
,, 11	136	7·0	85·2	0·9	1 : 95
,, 14	147	10·0	97·5	0·7	1 : 139

* Data on ' number of tillers per clump ' given from the counting of two clumps. Other figures are given from 10 measurements in each case

TABLE I *contd.*

* *Data on tillering and other stem and leaf characters in mature plants (8 to 9 months old)*

Type number	Total number of tillers per clump	Length of buds in mm.	Lamina size		Leaf module
			Length in cm.	Breadth in cm.	
SES 15	35	6·0	80·8	1·0	1 : 81
,, 29	114	6·0	79·5	1·2	1 : 66
,, 31	135	6·0	85·8	1·2	1 : 72
,, 32B	95	8·0	115·5	1·0	1 : 116
,, 34	62	8·0	114·8	1·2	1 : 96
,, 38	92	6·0	97·8	1·2	1 : 82
,, 44	77	8·0	120·0	1·0	1 : 120
,, 45	110	6·0	90·5	1·2	1 : 75
,, 50	50	7·0	88·6	1·1	1 : 81
,, 65	32	8·0	125·5	1·0	1 : 126
,, 66	168	6·0	120·5	1·3	1 : 93
,, 69	84	6·0	104·0	0·7	1 : 149
,, 70	30	6·0	116·5	0·8	1 : 146
,, 72	140	6·5	126·5	0·8	1 : 158
,, 73	32	7·5	116·3	1·1	1 : 106
,, 74B	62	7·0	121·2	1·0	1 : 121
,, 76	60	7·0	124·5	0·7	1 : 178
,, 78	47	6·0	117·5	1·1	1 : 107
,, 80A	23	7·0	120·2	0·9	1 : 134
,, 81	82	7·0	113·5	0·8	1 : 142
,, 84B	55	7·0	118·0	1·0	1 : 118
,, 85D	7	7·6	95·5	1·0	1 : 96
,, 87A	40	7·5	128·5	0·9	1 : 142
,, 88C	58	8·0	135·0	0·6	1 : 225
,, 91	27	10·0	150·0	1·6	1 : 94

* Data on 'number of tillers per clump' given from counting of two clumps. Other figures are given from 10 measurements in each case.

According to habit, the variant forms of *S. spontaneum* can be clearly distinguished into 3 groups (i) *erect*, (ii) *suberect*, and (iii) *prostrate* or *trailing*. Root-dissections of five types show that the erect types have comparatively deeper and more compact root-system, while the sub-erect or trailing types have a shallower and more spreading root system. The different habit-forms can be co-related with the mode of underground branching. In the *erect* types with tufted, closely aggregated branches, the characteristic appearance is due to the first shoot being erect, and the secondary shoots sprouting immediately from the closely aggregated underground nodes of the parent culm, and growing upwards almost parallel to it. In the *prostrate* types (e.g., SES 1,11 etc.) on the other hand, the axillary buds on the parent culm grow outwards in all directions to considerable length and lie horizontally underground. The prostrate nature is due to the axillary buds on these secondary shoots sprouting much later than those on the parent culms and growing in a subvertical or horizontal direction. The *suberect* types (e.g. SES 45) are intermediate between these two forms. All the types studied show monopodial branching. This confirms Barber's [1919] observation that both the tufted and decumbent forms of *S. spontaneum* have the same mode of growth. Panje [1933], however, suggested that the ' Indian ' forms have a monopodial and the ' East Indian ' forms a sympodial mode of branching. Variation in different parts of the plant is discussed below (Plate XXIV, fig. 1).

Culms. The variation in colour of the canes cannot be taken as characteristic. The culms vary from 97·5-407 cm. in length and 6-10 cm. in thickness and contain 10-34 internodes. Grooves along the internode (characteristic of *Erianthus*) are generally absent, but shallow depressions are present in some types (SES 14, 32B). The variation in *growth ring* patterns does not appear to be characteristic. The *root zone* varies from 4-8 mm. in width, and contains $1\frac{1}{2}$ (SES 78), 2 (SES I), or $2\frac{1}{2}$ (SES 74B) rows of *root eyes* supplying characteristic features of differentiation. A *circlet of hairs* is commonly absent or inconspicuous.

The buds vary in size and shape (Plate XXIV, fig. 2). They are ovate (SES 6), obovate (SES 84B), roundish (SES 1), oval (SES 73), oblong (SES 14) or rhomboid (SES 85D). The germ-pore may be apical or subapical (SES 44), and the *wings* on the prophyll are narrow (SES 32B) or broad (SES 91), usually covered with characteristic short (SES 1) or long hair groups (SES 44), which may be sparse or dense. Much stress has been put on the characters of bud by Barber [1915, 1918-19] and Artschwager [1942]. Jeswiet [1916] laid special stress on the hair groups on the buds but a thorough analysis of these hair groups is very time absorbing. In consideration of the above points, it appears that the shape of the buds, the position of their germ pores, the wing patterns including the length and density of hairs on them, will supply important distinguishing features for the different types.

Leaves. The leaf sheath is usually green, sometimes light or deep pink especially in sprouting shoots, generally glabrous, rarely with deciduous or persistent bristles (e.g. SES 32B, 50). The *sheath base* is usually straight rarely slightly decurrent (SES 84B), and sometimes surrounded by a conspicuous ring of hairs (SES 32B).

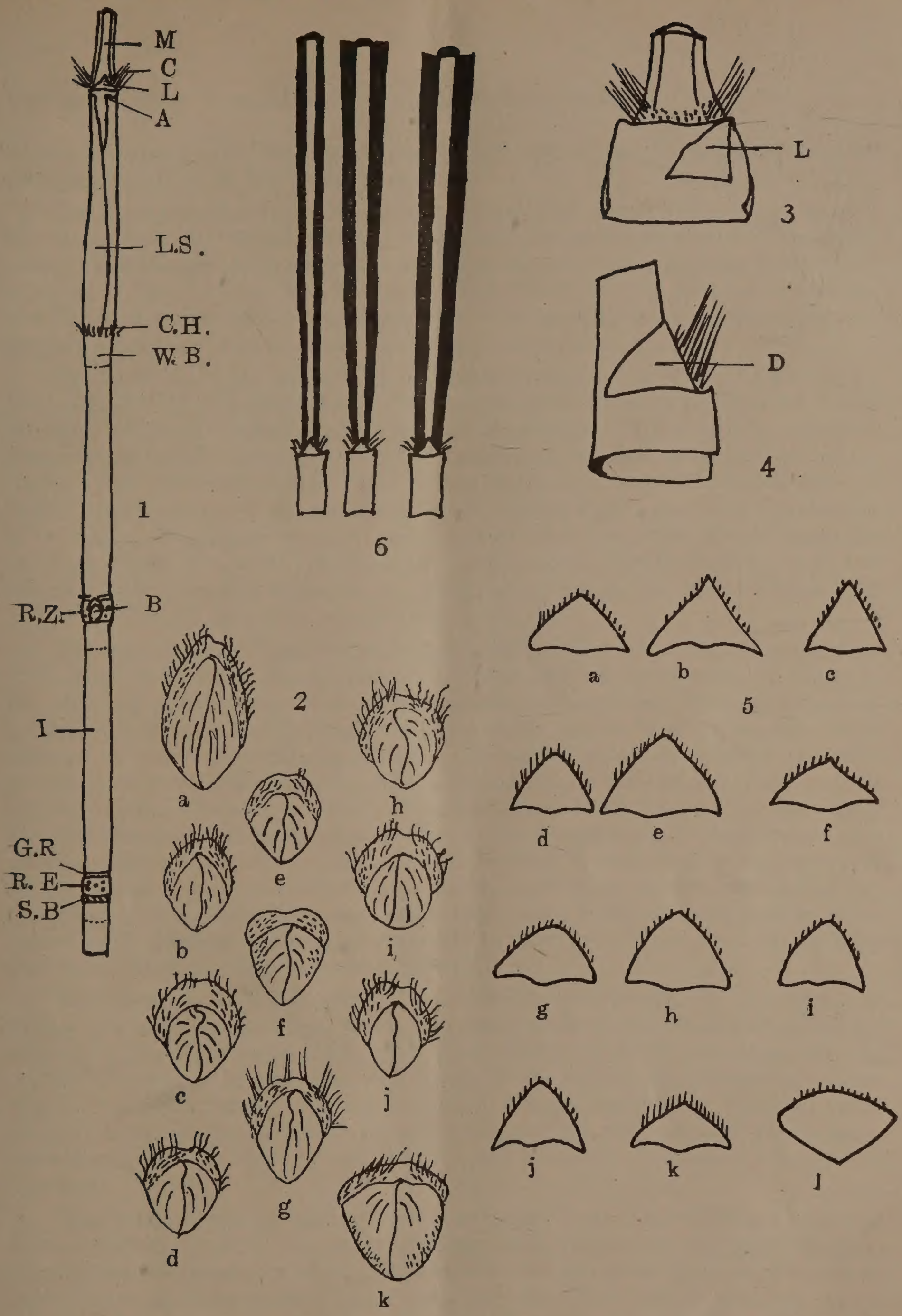


FIG. 1—6. Diagrammatic drawing of the vegetative organs.

1. Different parts of a culm: M—midrib, C—cilia, L—Ligule, A—aur cle, L. S.—leaf sheath, C. H.—circlet of hairs at node, S. B.—Sheath base, I.—internode, R. E.—root eyes, B.—bud, W. B.—Waxy band, R. Z.—root zone, G. R.—growth ring, S. B.—scar band;
2. Variations in bud: a—SES 34, b—SES 29, C—SES 87A, d—SES 69, e—SES 85D, f—SES 84B, g—SES 50, h—SES 70, i—SES 4A, j—SES 45, K—SES 91.
3. Inner surface of the blade joint with ligule (L);
4. Side view of the blade joint showing dewlap (D);
5. Variations in ligule: a—SES 50, b—SES 74B, C—SES 66, d—SES 11, e—SES 32B, f—SES 65, g—SES 38, h—SES 8, i—SES 45, j—SES 76, k—SES 69, l—SES 84B.
6. Variations in width of the lamina at blade joint.

It may have hairy (SES 38) or glabrous margins (SES 1), but Panje [1933] observed a smooth sheath in all the Indian forms.

The *blade joint* has two surfaces (Plate XXIV, figs. 3 and 4) the inner forming the *throat* and the outer forming *collar*, containing the *dewlap* or 'transverse mark', which is generally triangular or wedge-shaped, rarely ligulate (SES 66) or squarish. The shape of dewlap is not so important, but the presence or absence of hairs on the outer surface is characteristic. The inner surface is always hairy and the throat contains conspicuous tufts of long or short hairs.

The *ligule* is usually deltoid with a rounded or angular tip (Plate XXIV, fig. 5), but in SES 84B it is inverted deltoid. It varies from 6-11 mm. in width and 4-7 mm. in height, and possesses long or short hairs at the margin. It has mainly deltoid or crescentiform shape, characteristic of the Indian and the East Indian forms respectively. But the South Indian types possess variants of only the deltoid type of ligule. Their size and shape are constant and therefore quite useful in delimitation of the types. The ligular process or *auricle* is an extension of the sheath margin on the blade joint. It is quite prominent in *S. officinarum* [Barber 1915 to 1919], but reported to be generally absent in *S. spontaneum*. Among the present types SES 74B and 88C have, however quite prominent auricles.

The lamina varies from 80-150 cm. in length, and 0·6 to 1·6 cm. in breadth. It is short in prostrate forms, medium in dwarf and sub-erect forms, and long in the erect and robust forms. Three clear types can be recognized (Plate XXIV, fig. 6) according to the width of the blade at blade joint or lamina base (1) : lamina almost reduced to midrib throughout its length, (2) lamina gradually reduced to midrib at base from the middle portion, and (3) lamina almost unreduced at base or very slightly reduced [Mukherjee, 1949]. The characters of the lamina have previously supplied important diagnostic features in the classification of *S. spontaneum* forms [Hackel, 1889 ; Hole 1911]. Barber [1915 to 1919] found them quite important for sugarcane. Panje and Artschwager placed more stress on the leaf-module (i.e. the ratio of breadth/length), and found the Indian forms to have leaf modules exceeding 1 : 100 but the present study shows that some types have leaf-modules less than 1 : 100, as will be seen from Table I.

Inflorescence. It is a terminal panicle varying from 30·5-70 cm. in length. It is generally lanceolate in shape, but types with pyramidal, elliptic, oblong or oblong-lanceolate panicles are also found [Mukherjee, 1949]. The different shapes are due to the variation in arrangement and length of the inflorescence branches. Two types of panicles having different branching pattern are mainly found (1) with primary axes bearing secondary branches only and (2) with primary axes bearing secondary branches, which in turn bear tertiary branches. The latter type is more common.

The primary axis (peduncle) carries secondary branches, which are long and sub-verticellate at base, but short, compact and whorled at the upper portion. The distance between the whorl of branches varies and gives the compact or loose appearance to the panicle. These branches ultimately bear articulated rachae (*rachis joint*) of varying length bearing a pair of spikelets, one sessile and the other

pedicelled; the latter opening first. Each spikelet is uniflowered, hermaphordite, and surrounded by a group of hairs (*callus hairs*), 1-3 times its length (4-5·8 cm.).

Each spikelet consists of an outer binerved glume (*Glume I*) embracing a boat-shaped, single nerved glume (*Glume II*) within. They are generally equal in length, lanceolate or ovate-lanceolate; margins variously ciliated; chartaceous to hayline above and subcoriaceous to coriaceous near the base. They have various shades of pink patches at base and 1·1-2·0 mm. wide; II being slightly wider than I. The *sterile lemma* or *glume III* is much more delicate, nerveless, hayline, ovate or oblong-lanceolate, acute, ciliated at margins, and 2·9-4·6 mm. long. The *fertile lemma* or *glume IV* is always linear, membraneous, variously ciliated and 0·9-4·5 mm. long. The *palea* is minute (sometimes smaller than lodicules), variable, hayline, ciliated at upper margin. Every flower has 2, short, cuneate or wedge-shaped, thick and fleshy lodicules, ciliated at upper margin. Stamens are 3 in number, variously pigmented (yellow to deep pink). The ovary bears two feathery stigmas which vary in length (1·3-2·4 mm.), and colouration.

Since the establishment of the species by Linnaeus [1771], the floral characters had been taken as very important for classification by subsequent workers. Hackel [1889] divided it into two sub-species, *indicum* and *aegyptiacum*, on the characters of the inflorescence and spikelet; the former being characterised by slender, lax-flowered racemes, 3-4 mm. long spikelets, and the length of callus hairs to spikelet bearing a ratio of 4-6. But the present collection shows that the Indian forms have both lax and dense flowered panicles and have long spikelets in some (4-5·8 mm.), characteristic of the subsp. *aegyptiacum*. Hence Hackel's separation of the two subspecies on floral characters does not appear to be tenable. Hooker [1897] observed that the Glume IV is usually absent in *S. spontaneum*, but it has been found to be invariably present in all the types studied, although much smaller in size. Jeswiet [1925] also found its presence and suggested it to be a distinguishing character from *S. officinarum*, in which glume IV is mostly absent. Panje [1933] considered that no groupings among the Spontaneums are possible on inflorescence characters. Artschwager [1942] also did not put any stress on them. The present observation indicates that the shape and size of the inflorescence and the nature of their branching, the size of glume IV, and the colour of anthers and stigma are likely to form important additional characters for grouping of the various types. An intensive study of these characters may also lead to the elucidation of its phylogenetic relationship with the remaining species of the genus i.e. *S. officinarum*, *S. robustum*, *S. barberi* and *S. sinense*.

ANATOMICAL STRUCTURES AND THEIR VARIATION

Artschwager [1925, 1930, 1942], and Panje [1933] found that *S. spontaneum* has almost similar gross anatomical features as in sugarcane. Although the present observation does not show much difference in the stem anatomy of the different types, variations in the structure of the stem and leaf epidermis patterns are quite distinctive in most types.

Data regarding the following characters in the stem epidermis : (1) number of long cells per unit area, (2) width of the long cells, (3) nature of wall of the long cells, (4) arrangement of the short cell groups, (5) number of cork-cells, (6) number of silica cells, (7) number of solitary cork cells, (8) number of solitary silica cells are given in the Table II.

TABLE II

Measurement and count of cells of stem and leaf epidermis in different types

Type number	Steam epidermis					Leaf epidermis					
						Lower			Upper		
	Number of long cells	Width of long cells in μ	Number of cork-silica cell groups	Number of solitary cork cells	Number of solitary silica cells	Number of asperites (spines)	Stomata Number or rows	Stomata Total number	Number of rows of bulliform cells	Stomata Number of rows	Stomata Total number
SES. 1	24	5·2	14	2	4	14	2	14	4	1—2	3
,, 4A	33	7·4	30	1	1	17	1	9	4	1—2	4
,, 6	22	8·1	19	x	3	8	1	6	5	1	4
,, 8	29	6·8	23	x	1	11	1—2	8	5	1	3
,, 11	33	5·2	22	5	2	11	1—2	8	4	1—2	5
,, 14	27	6·1	20	2	6	15	1	9	3	1	6
,, 15	30	7·3	26	1	1	13	1	10	3	1—2	4
,, 29	36	7·5	34	1	x	13	1	7	3	1	5
,, 31	35	7·8	25	8	1	13	1	8	3	1	5
,, 32B	28	7·1	22	x	1	18	1	8	2	1	5
,, 34	32	7·4	21	x	1	13	1	6	4	1	3
,, 38	26	7·7	22	x	2	6	1—2	6	4	1	4
,, 44	22	6·8	15	3	1	13	1	6	4	1	4
,, 45	35	5·6	28	2	1	13	1	10	2	1	4
,, 50	30	6·8	29	1	x	7	2	7	4	1	3
,, 65	29	5·7	25	x	2	11	1	6	3	1	5
,, 66	17	7·3	16	x	x	8	1—2	8	2	1	5
,, 69	25	6·6	22	x	4	8	1	7	3	1—2	4
,, 70	40	5·7	40	x	1	14	1	7	3	1	3
,, 72	27	6·2	20	x	2	18	1—2	13	3	1	5
,, 73	24	6·3	21	x	2	12	2	12	3	1—2	5
,, 74B	29	6·8	26	x	1	6	1—2	6	3	2	4
,, 76	32	7·6	28	5	x	13	1	6	3	1	5
,, 78	30	5·7	26	x	4	12	1	9	5	1—2	4

TABLE II—*contd.*

Measurement and count of cells of stem and leaf epidermis in different types

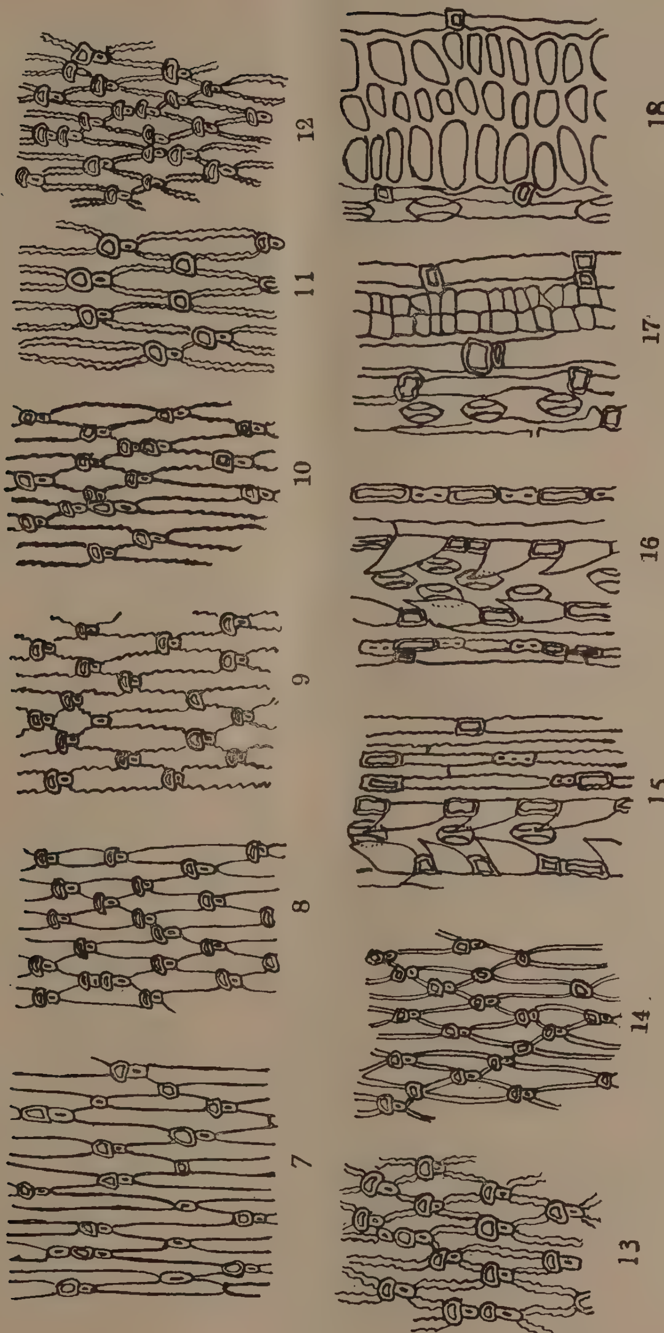
Type number	Stem epidermis					Leaf epidermis					
						Lower			Upper		
	Number of long cells	Width of long cells in μ	Number of cork-silica cell groups	Number of solitary cork cells	Number of solitary silica cells	Number of asperites (spines)	Stomata: Number of rows	Stomata: Total Number	Number of rows of bulliform cells	Stomata: Number of rows	Stomata: Total number
SES 80A	40	5·6	34	x	9	7	1—2	6	4	1	2
,, 81	27	5·8	23	1	3	13	1—2	11	3	1	4
,, 84B	27	6·8	17	2	x	16	1—2	8	4	1	5
,, 85D	32	6·7	30	x	x	9	2	12	3	1—2	5
,, 87A	36	5·4	33	x	2	15	1—2	12	3	1	5
,, 88C	24	7·9	19	x	x	9	2	9	3	1	6
,, 91	18	9·8	14	1	x	16	1	8	3	1	3

Considerable variation is observed within the different forms in most of the above characters, which can therefore be used for identification of different types. The long cells per unit area ($\frac{1}{5}$ mm. square) vary from 17-40 in number, and have characteristic straight or wavy walls, which may be thick or thin (Plate XXV, figs. 7-14).

The cork and silica cells are mostly in pairs; but the different types vary in having them in single or multiple pairs. The cork cells are roundish, rhomboid, kidney shaped, or rarely elliptic or horseshoe-shaped; while the silica cells are roundish, elliptic or squarish. Solitary cork and silica cells, although rare in *Saccharum*, have been found in some forms.

The leaf anatomy of the *S. spontaneum* is of the general pattern characteristic of the grasses. A transverse section shows three types of bundles (1) the large bundles found at wide intervals corresponding to the big veins, girdered on both sides by sclerenchymatous caps touching the epidermis; (2) the medium bundles with sclerenchymatous caps also touching both epidermis, but smaller in size; and (3) the small bundles, only touching the lower epidermis and having no diffentiation of meta or protoxylem.

The upper epidermis is generally smooth, while the lower one has grooves wherein the stomata are located. Bulliform cells are found in the upper epidermis in between the bundles (Plate XXV, figs. 17-18). The epidermis is divisible into two regions: (1) the veinous region directly above the veins or vascular bundles, and (2) the costal region representing the area between the bundles.



FIGS. 7—18. Variations in stem epidermis patterns : 7—SES 1, 8—SES 85D, 9—SES 15, 10—SES 74B, 11—SES 44, 12—SES 70, 13—SES 72, 14—SES 11. 15—16 Structure of lower epidermis of leaves : 15—SES 29, 16—SES 74B. 17—18. Structure of upper epidermis of leaves : 17—SES 66, 18—SES 28. (×400).

In the lower epidermis, the cork and silica cells are present in the veinous region usually in pairs, rarely solitary. Stomata in single or double rows (Plate XXV, figs. 15-16) are usually arranged sunk inside grooves and protected by spines bordering the grooves. The number of spines and stomata per unit area appear to be characteristic for each type.

The veinous region in the upper epidermis shows the same pattern as the lower epidermis. In the costal region, the number of rows of bulliform cells is characteristic, and varies from 2 to 5 in different types. The stomata are arranged on either side of the bulliform cells in single or double rows. Table II gives the distribution of stomata, spines and bulliform cells in the leaf-epidermis. The following characters appear to vary significantly in the different types : (1) the nature and arrangement of the asperites or spines and their number per unit area in the lower epidermis, (2) the number of rows of bulliform cells in the upper epidermis, (3) the number of rows of stomata, their distribution and number per unit area on both surfaces, (4) presence or absence of joint spines.

Polymorphism in *S. Spontaneum* and the status of variants

A study of the variation in the morphological and anatomical characters discussed above shows that *S. spontaneum* is a highly polymorphic species. Perhaps in no other wild species such a huge amount of variation has been recorded. 'The evidences from the chromosome numbers show that the evolution of *S. spontaneum* species has progressed mainly through polyploidy, though some aneuploid forms also exist' [Parthasarathy and Subba Rao, 1946]. Future observations on the genetics of these types will help very much in determining the fundamental nature of such polymorphism.

The variants of *S. spontaneum* have been given the category of 'clone' by Artschwager [1942] as these are maintained in collections through clonal propagation. But such diversity is also produced in nature due to the reaction of the plants to the environment. Till the character differences among the types are found to be hereditary or non-hereditary we may recognize them as 'putative ecads' as suggested by Salisbury [1940]. The variant types occurring in nature are propagated both by seeds and rhizomes. But further extension of its area is taking place mainly through the dispersal of light airborne seeds to long distances, and their germination and growth in 'open habitats'. These plants are generally found in open areas along the river bed or bank and on new clearings and waste-lands. It is significant that the statement of Salisbury [1940] that the 'species of open habitats where competition is least severe often display a variety of races' supplies the probable explanation for variations in this species. As the new types, that are being produced are readily intercrossable, natural hybridisation has also been an important factor in its evolution ; their compatibility being established from controlled crossings. This plasticity tends to lead to continuity of occupation over a wide range of habitat conditions, as has been found from the wide area of distribution of *S. spontneum* from the Caspian Sea in Central Asia, 48°F. of Green wich, to Society Island 139W°., included within a latitudinal range of 62°..

Whether the variant 'forms' or 'putative ecads' are in the process of formation of true 'ecotypes' may be determined by future genetical experiments to find out if they are 'genetically and physiologically distinct' and adapted to different environments. 'Ecotypes' of one species have the same internal balance, for there is no genetic obstacle to a free interchange of their genes when they meet and hybridize. Each of such ecotypes, however, strikes a different balance with the environments by natural selection [Clausen, Keck and Hiesey, 1945]. Future work on these lines will elucidate the nature of evolution in *Saccharum* and the fundamental nature of species formation in general. The plasticity within the species and ready intercrossability with the sugarcanes (*S. officinarum*, *S. Barberi*, and *S. sinense*) have proved very useful for evolving new types of canes for the purpose of improving the crop.

Key to the types of S. spontaneum studied

A key for identification of 31 types and a description of the more important and distinct types among them are given below. The distinguishing features of each type are given in italics. The schedule of characters employed in description of the different types is given in Appendix I at the end.

Habit erect

A. Lamina almost reduced to midrib throughout; leaf module above 200; auricle prominent; stem epidermis with single and multiple pair of rock-silica cells, bulliform cells in 3 rows in leaf epidermis.......... *SES 88C*

AA. Lamina almost unreduced at blade joint.

B. Leaf module above 100.

C. Root eyes $2\frac{1}{2}$ staggered rows; prominent auricle on one side; stem epidermis with thin wavy walls; bulliform cells in 3 rows in leaf epidermis.......... *SES 74B*

CC. Root eyes $1\frac{1}{2}$ row; auricle absent; stem epidermis with thick straight walls; bulliform cells in 5 rows in leaf epidermis.......... *SES 78*

BB. Leaf module below 100.

D. Auricle completely absent; buds elliptic, elongated; stem epidermis with thick, wavy walls; bulliform cells in 2 rows in leaf epidermis.......... *SES 66*

DD. Auricle slight or indicated; buds oval or ovate.

E. Leaf sheath prominently hairy at back; bulliform cells in leaf epidermis; stem epidermis with thin, wavy walls.......... *SES 50*

EE. Leaf sheath glabrous at back; bulliform cell in 3 rows in leaf epidermis; stem epidermis with thick wavy walls and cork-silica cells in multiple pairs.......... *SES 73*

AAA. Lamina gradually reduced to midrib at blade joint.

F. Leaf module below 100.

G. Bud ovate with prominent broad apical wing: auricle present on both sides; bulliform cells in 3 rows in leaf epidermis..................*SES 91*

GG. Bud elliptic-oblong; auricle slight on one side; bulliform cells in 4 rows in leaf epidermis...*SES 34*

GGG. Bud ovate; auricle indicated only; bulliform cells in 5 rows in leaf epidermis...*SES 6*

FF. Leaf module above 100.

H. Root eyes in $2\frac{1}{2}$ staggered rows in the root zone.

I. Buds ovate-elliptic.

J. Bulliform cells in 2 rows in leaf epidermis dewlap hairy...*SES 32B*

JJ. Bulliform cells in 3 rows in leaf epidermis; dewlap glabrous...*SES 76*

II. Buds roundish.

K. Ligule broad, deltoid; auricle indicated; dewlap hairy; stem epidermis with thin wavy walls..................................*SES 65*

KK. Ligule tall triangular; auricle absent; dewlap glabrous; stem epidermis with thick wavy walls..........................*SES 87A*

HH. Root eyes in $1\frac{1}{2}$ or 2 rows in the root zone.

L. Auricle completely absent.

M. Buds elliptic—oblong, big; dewlap squarish..............*SES 14*

MM. Buds roundish, small; dewlap tringular.

N. Dewlap hairy; ligule low with long hair....................*SES 69*

NN. Dewlap glabrous; ligule tall with shorter hairs.........*SES 70*

LL. Auricle indicated or slight.

O. Ligule pointed triangular with long narrow flanges; dewlap hairy; bulliform cells in 4 rows in leaf epidermis ....*SES 80A*

OO. Ligule dome-shaped with very short flange; dewlap glabrous.

P. Bulliform cells in 4 rows in leaf epidermis..................*SES 44*

PP. Bulliform cells in 3 rows in leaf epidermis................*SES 72*

Habit suberect

A. Ligule inverted deltoid; buds ovate with short apical wing; auricle present on two sides...*SES 84B*

AA. Ligule triangular de'toid; buds ovate or rhomboid; auricle slight or transitional.

B. Leaf module above 100; lamina gradually reduced to midrib at blade joint; stem epidermis with thick wavy walls ....*SES 81*

BB. Leaf module below 100 ; lamina almost reduced to midrib blade joint.

C. Bud ovate with unequal wings ; ligule dome-shaped with rounded apex ; stem epidermis with thick straight walls............................*SES 45*

CC. Buds rhomboid with subapical wings ; ligule triangular with acute apex ; stem epidermis with thin straight walls................*SES 85D*

Habit trailing or *prostrate*

A. Lamina almost unreduced at blade joint.

B. Ligule triangular with acute apex ; bud roundish with narrow wing ; leaf sheath with glabrous margin..*SES 1*

BB. Ligule dome-shaped with rounded apex ; bud roundish with broad wing ; leaf sheath hairy at margin..*SES 38*

AA. Lamina gradually reduced to midrib at blade joint.

C. Leaf module above 100 ; bulliform cells in 5 rows in leaf epidermis ; stem epidermis with thin straight walls..*SES 8*

CC. Leaf module below 100 ; bulliform cells in 3 or 4 rows.

D. Bulliform cells in 3 rows in leaf epidermis.

E. Ligule dome-shaped ; dewlap hairy ; stem epidermis with thin wavy walls...*SES 29*

EE. Ligule triangular with pointed apex ; dewlap glabrous.

F. Leaf sheath margin glabrous ; auricle indicated ; stem epidermis with thin wavy walls....................................*SES 15*

FF. Leaf sheath margin hairy ; auricle absent ; stem epidermis with thin straight walls....................................*SES 31*

DD. Bulliform cells in 4 rows.

G. Stem epidermis with thin, straight walls ; stem medium (8-10 mm. thick)...*SES 4A*

GG. Stem epidermis with thick, straight walls ; stem thin (6-8 mm. thick)..*SES 11*

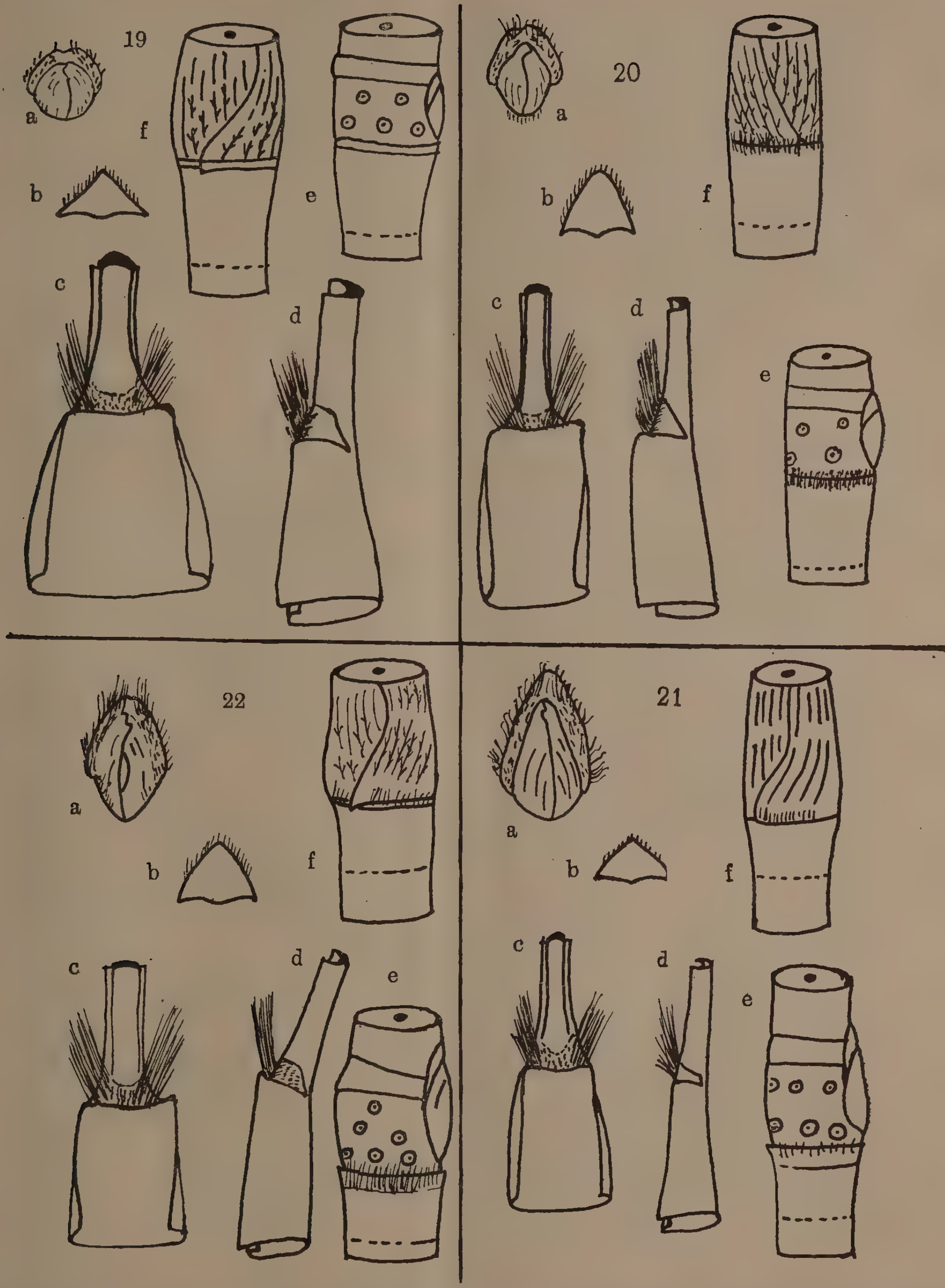
Description of the types

SES.† 1. (Plate XXVI, fig. 19).

Collected from : South Kanara—Madras ; growing on saline sandy soil mixed with alluvial deposit on river-bank about one mile from sea.

Habit. Trailing ; stem thin, medium tillering. *Culms* : *purple*, waxy, bloom fairly heavy ; internodes medium, 5-6 mm. thick ; root zone about 5 mm. wide, obconoidal, with two staggered rows of root eyes. Bud at node, roundish, small ; germpore apical ; wing narrow with rounded and emarginate tip, hairs short. *Stem epidermal cells long with straight thin wall ; cork and silica cells in pair as well as single.*

† SES represents Spontaneum Expedition Scheme collection.



FIGS. 19—22. Diagnostic features of the different types—FIG. 19—SES I; 20—SES 6; 21—SES 14; 22—SES 32 B. a—bud, b—ligule; c—blade joint showing the lamina, cilia and throat; d—side view of blade joint showing dewlap; e—nodal region of stem showing the growth ring, root zone with root eyes, position of bud, and scar band.

Leaves. Leaf sheath green with pinkish tinge around base and light waxy bloom; *short bristles* on young sheaths; base very slightly decurrent; dewlap ligular with hairs at margin; auricle absent; ligule medium broad, triangular deltoid with marginal fringe of very short hairs. Lamina short, medium broad (leaf module—1 : 89), not completely reduced to midrib at base. *Upper epidermis spiny; lower epidermis with stomata in 2 rows. Inflorescence*: Panicle lanceolate 40·5 cm. long, tertiary branches common; spikelets arise sufficient above base of rachae, close, 5·8 mm. long; rachis joint 7 mm. long; pedicel about $\frac{3}{4}$th the spikelet; callus hairs dense, above 3 times the spikelets; glumes I and II brown, without pigmentation, glume III sparsely ciliated; glume IV linear, nonciliate, 3·8 mm. long; anthers brown, 2·5 mm. long; stigma light purple, 1·5 mm. long.

SES. 6. (Plate XXVI, fig. 20).

Collected from: South Kanara, Madras; growing on loam soil mixed with humus, at margin of a narrow water-channel in the plains.

Habit: Tufted, *open erect;* stem medium thick, good tillering. *Culms* yellowish to reddish brown, heavily waxed throughout; internodes medium, 7-8 mm. thick; root zone about 6-7 mm. wide, with two staggered rows of root eyes. Bud arises from root zone slightly above scarband, *ovate*, medium, germpore sub-apical; wing inserted at or slightly below the middle of prophyll, tip broadly rounded, small hairs at margins and back. *Leaves*: Leaf sheath green *with pinkish purple tinge* and light waxy bloom; circlet of long hairs present around node; sheath base straight; dewlap medium high, triangular, with short marginal hairs; auricle transitionary; *ligule tall, deltoid*, with conspicuous marginal fringe of medium long hairs. Lamina medium; leaf module 1 : 95; *reduced to midrib for about 15-16 cm. from base.*

Inflorescence: Panicle lanceolate, 66·5 cm. long, tertiary branches common; spikelets lax and arise much above the base of rachae; rachis joint 7·9 mm. long; pedicel almost equal to spikelet; callus hairs dense, about 3 times the spikelet; glume I and II pinkish brown at margin and base; glume III densely ciliated; glume IV linear, non-ciliate, 2·7 mm. long; anthers deep yellow, 2·1 mm. long; stigma light purple 1·6 mm. long.

SES. 14. (Plate XXVI, fig. 21).

Collected from: South Kanara—Madras; growing on clay soil in rice-field at 3,000 ft. on the Western Ghats.

Habit: *Dwarf*, open erect; stem medium thick, good tillering; *flowers throughout the year. Culms* yellowish brown, heavily waxed; internodes short, biconcave, occasionally with shallow groove above the bud 7 mm. thick; root zone 5-7 mm. wide, conoidal with 2 staggered rows of root eyes. Bud arises slightly above scarband, *elliptic oblong*, big; germpore apical; wing inserted almost at base, medium broad with obtuse tip, densely hairy.

Leaves: Leaf sheath light green with very light pink patch, very light waxy bloom; sheath base straight; dewlap low, squarish; auricle absent; ligule

medium broad, triangular deltoid with marginal fringe of short hairs. Lamina medium, narrow (leaf module 1 : 139) ; *reduced to midrib for 1-2 cm. at base.*

Inflorescence : Panicle conical, 32·5 cm. long ; tertiary branches few, at base only ; spikelets arise much above the base of rachae, 4·5 mm. long, lax ; rachis joint 6·8 mm. long ; pedicel as long as spikelet ; callus hairs very dense, about 3 times the length of spikelets ; glumes I and II with scarlet patch above base ; glume III densely ciliated ; glume IV linear, reduced, hyaline, ciliated towards tip along margin, 2·1 mm. long ; stigma deep purple, 1·5 mm. long.

SES. 29

Collected from : Malabar—Madras ; growing on moist sandy soil along a rivulet inside deciduous forest. *Habit* : *Dwarf, spreading*, stem thin, medium tillering. *Culms* pale yellow to light yellowish brown, waxy bloom fairly heavy ; internodes short, 5-6 mm. thick ; root zone 5-6 mm. wide, with two alternating rows of inconspicuous root eyes. Bud at node, ovate, small to medium ; germpore apical ; wing inserted slightly below the middle, narrow with tips rounded and emarginate, medium long hairs at margin, apex and back. *Epidermis with wavy walls, and cork-silica cells always in pairs. Leaves* : Leaf sheath green with pinkish patches and very light waxy bloom ; persistent circlet of hairs present around node ; sheath base straight ; *dewlap high, triangular, with rows of very short hairs ;* auricle absent ; ligule medium broad, dome-shaped, with short hairs. *Lamina short and broad* (leaf module 1 : 66), not completely reduced to midrib at base. *Epidermis with 3 rows of bulliform cells and stomata in 1 row. Inflorescence* : Panicle lanceolate, 30·8 cm. long, tertiary branches only at base ; spikelets arise slightly above base of rachae, lax, 5·3 mm. long ; rachis joint 6·7 mm. long ; pedicel about $\frac{3}{4}$th of spikelet ; callus hairs medium dense, about $2\frac{1}{2}$ the length of spikelets ; glumes I and II with a scarlet patch above coriaceous base ; glume III reddish in the middle, densely ciliated ; glume IV linear, sparsely ciliated along one margin, 3·6 mm. long ; anthers yellow, 2·3 mm. long ; stigma light maroon pink, 2·4 mm. long.

SES. 32 B. (Plate XXVI, Fig. 22)

Collected from : Malabar—Madras ; growing on dry sands at margin of river bank by the cultivated fields. *Habit* : *Open spreading erect* ; stem ascending, medium thick, good tillering. *Culms* reddish to yellowish brown, waxy bloom fairly heavy ; internodes short to medium, short shallow groove just above bud, 7 mm. thick ; root zone 6—7 mm. wide, obconoidal, with $2\frac{1}{2}$ staggered rows of root eyes. Bud slightly above scar band, *oblong ovate*, medium ; germpore apical ; wing inserted slightly below the middle of prophyll, tip rounded and slightly emarginate, medium long hairs at margins, apex and back. *Epidermis with long cells having straight wall* ; *cork-silica cells mostly in pairs, few solitary cells. Leaves* : Leaf sheath green with big reddish pink patches at back and margins and very light waxy bloom ; circlet of short hairs around node ; sheath base very slightly decurrent ; very short and persistent bristles on back, and short hairs at margin of sheath near blade joint ; *dewlap* low, ligular, *with rows of very short hairs* ; auricle slightly indicated ; ligule medium broad, dome-shaped, deltoid with marginal fringe of short hairs.

FIGS. 23—26. Diagnostic features on different types; FIG. 23—SES 44; 24—SES 66; 25—SES 73, 26—SES 74B.

Lamina medium (leaf module 1 : 116), reduced to midrib for about 6-7 cm. from base. *Inflorescence* ; Panicle lanceolate, 42·5 cm. long ; tertiary branches present at base only ; spikelets arise from base of racheae, lax, 5·6 mm. long ; rachis joint 6·9 mm. long ; pedicel about ¾ the spikelet ; callus hairs medium dense, about 2½ times spikelet ; glumes I and II whitish brown without pigmentation ; glume III very broad, mediumly ciliated ; glume IV linear, broader in the middle, ciliated at apex, 3·4 mm. long ; anthers deep yellow, 1·8 mm. long ; stigma maroon pink, 1·8 mm. long.

SES. 44 (Plate XXVII, Fig. 23)

Collected from : Coimbatore—Madras ; growing on moist clay soil inside swamp in a Tea estate on the Annamalai Hills at 2,000 ft. *Habit* ; *Open, erect, tall ; stem thick*, stout, good tillering. *Culms* : *brown*, heavily waxed ; *internodes long*, 11 mm. across ; root zone about 7 mm. wide, with 2 alternating rows of root eyes. Bud at node, *oval*, medium ; germpore subapical ; wing inserted about the middle of prophyll, narrow with rounded tip, short and long hairs at margins, back and apex. *Epidermis with long cells having thick wavy walls, cork-silica cells in pair, also solitary cork cells. Leaves* : Leaf sheath green with light purple hue on exposed surfaces ; waxy bloom very light ; circlet of hairs absent ; sheath base straight ; dewlap low, triangular ; auricle very slightly indicated ; *ligule medium broad, dome-shaped ;* deltoid with very few short hairs on the margins. Lamina medium (leaf module 1 : 120) ; reduced to midrib for about 4-5 cm. from base. *Epidermis with bulliform cells in 4 rows. Inflorescence* : *Panicle oblong-lanceolate*, 75·5 cm. long ; tertiary branches common ; spikelets arise sufficiently above the base of racheae, lax, 4·6 mm. long ; rachis joint 6·9 mm. long ; pedicel about half the spikelet ; callus hairs about 3 times the spikelet ; glumes I and II brown with scarlet patch ; glume III hyaline, densely ciliated, with scarlet patch in the middle ; glume IV linear, mediumly ciliated along margins, 3·4 mm. long ; anther yellow, 2·3 mm. long ; stigma light purple, 1·5 mm. long.

SES. 66 (Plate XXVII, Fig. 24)

Collected from : Madura—Madras ; growing on moist loam soil along bunds of cultivated field at 1000 ft. *Habit* : open, erect, straight ; stem medium thick, good tillering. *Culms*: *light yellowish brown with reddish tinge*, fairly heavy waxy bloom; internodes long, 8 mm. across ; root zone about 6 mm. wide, slightly tumescent with 2½ staggered rows of root eyes. Bud arises slightly above scarband, *ovate to elliptic oblong*, variable in size from small to medium, germpore apical ; wings inserted slightly above base, narrow to medium wide with obtuse tip and *irregular margin*, medium hairs on margins, apex and back. *Epidermis with long cells having very thick wavy walls, cork-silica cells in pair. Leaves* : Leaf sheath green with few pinkish patches and light waxy bloom ; circlet of few short hairs present ; deciduous sheath base slightly decurrent ; dewlap medium high, ligular ; auricle absent ; *ligule tall triangular, pyramidal with marginal fringe of short hairs.* Lamina medium and broad (leaf module 1:93), not completely reduced to midrib at base. *Epidermis with 2 rous of stomata in lower surface, and 2 rows of bulliform cells on upper surfacc*

Inflorescence : Panicle conical, 50 cm. long ; tertiary branches common ; spikelets arise much above the base of racheae, lax, 5·1 mm. long ; rachis joint 6·5 mm. long ; pedicel about $\frac{3}{4}$ the spikelet ; callus hairs dense, about $1\frac{1}{2}$ times the spikelet ; glumes I and II whitish brown with a scarlet blotch ; glume III hyaline, mediumly ciliated ; glume IV linear, broader in the middle, ciliated along margins, 3·4 mm. long ; anthers pale yellow with pink tinge, 2·2 mm. long ; stigma deep maroon pink, 1·4 mm. long.

SES. 70

Collected from : Madura—Madras ; growing on dry sands along margin of a narrow dry stream in the plains at 1000 ft. *Habit* : *Open, erect;* stem medium thick, good tillering. *Culms* : *yellowish to reddish brown*, heavy waxy bloom ; internodes medium long, 8 mm. across ; root zone about 6 mm. wide, with 2 staggered rows of root eyes. Bud arises slightly above scar band, *oval*, small ; germpore subapical ; wing inserted at about $\frac{1}{3}$ of its length from base, broad with *tip truncated, long and medium hairs at margin*, apex and back. *Epidermis with long cells having thick wavy walls alternating with cork-silica cells in single and multiple pairs. Leaves* : Leaf sheath green with pink patches at back and margins ; circlet of small deciduous hairs present ; sheath base straight ; dewlap small, triangular ; auricle absent *ligule medium, tall deltoid, with marginal fringe of medium hairs.* Lamina medium (leaf module 1 : 146), reduced to midrib for about 15-16 cm. from base. *Inflorescence* : Panicle oblong-lanceolate, 41·8 cm. long ; tertiary branches present at base only ; spikelets arise from the base of racheae, close, 4·4 mm. long ; rachis joint 5·2 mm. long ; pedicel about half the spikelet ; callus hairs medium dense, about $3\frac{1}{2}$ times the spikelet ; glumes I and II light brown without pigmentation ; glume III densely ciliated ; glume IV long linear, ciliated, 4·1 mm. long ; anthers yellow, 2 mm. long ; stigma light purple, 1·6 mm. long.

SES. 73 (Plate XXVII, Fig. 25)

Collected from : Madura—Madras ; growing on coarse sands at margin of a dry water-channel. *Habit* : Open erect, ascending ; stem medium thick, medium tillering, *Culms* : *light yellowish brown with a reddish tinge*; with fairly heavy waxy bloom ; internodes medium, cylindrical biconcave, 8 mm. thick ; root zone about 7 mm. wide, slightly conoidal, tumescent, with 2 staggered rows of root eyes. Bud at node, *oval, medium* ; germpore subapical ; wing inserted slightly below the middle of prophylls, *with truncated round tip* with few short hairs. *Epidermis with long cells having thick wavy walls ; cork-silica cells in single, and multiple pairs and few solitary silica cells. Leaves* : Leaf sheath green with light purple hue and pink blotches ; circlet of hairs absent ; sheath base very slightly decurrent ; dewlap narrow, triangular ; auricle small, membranous ; *ligule broad, dome-shaped, deltoid* with marginal fringe of long hairs. Lamina medium, broad, not completely reduced to midrib at base. *Epidermis with bulliform cells in 2 rows. Inflorescence* : Panicle elliptic, 67 cm. long ; with few tertiary branches ; spikelets arise almost from base of the racheae, lax ; rachis joint 6·2 mm. long ; pedicel about helf the spikelet ; callus hairs medium dense, about 3 times the spikelet ; glumes I and II brown with

FIGS. 27—30. Diagnostic features of different types; FIG. 27—SES. 84B; 28—SES. 85D; 29—SES. 88C; 30—SES 91.

deep scarlet blotch above the coriaceous base and on margins ; glume III with a scarlet bloth at base, densely ciliated along margins ; glume IV linear, broader at middle, ciliated, 3·5 mm. long ; anthers yellow, 2·1 mm. long ; stigma light purple, 1·6 mm. long.

SES. 74 B (Plate XXVII, Fig. 26)

Collected from : Madura-Madras ; growing on moist sandy bank of Vaigai river in gregarious patches in the plains. *Habit :* Open, erect ; stem medium thick to thick, good tillering. *Culms : yellowish or reddish brown*, with heavy waxy bloom ; internodes long, 8-9 mm. thick ; root zone about 6 mm. wide, cylindrical, slightly conoidal, with 2½ staggered rows of root eyes. Bud at node, *oval, medium :* germpore subapical ; wing inserted about the middle of the prophylls, *broad with rounded tip*, short to medium long hairs at margin, apex and back. *Epidermis with long cells having thin wavy walls alternating with cork-silica cells in single and multiple pairs. Leaves:* Leaf sheath green with light purple tinge and conspicuous pink blotches ; circlet of hairs inconspicuous ; sheath base very slightly decurrent ; dewlap narrow, triangular ; *conspicuous auricle present ; ligule tall deltoid, pointed at tip and margin*, with medium long hairs. Lamina medium, not completely reduced to midrib at base. *Lower epidermis with stomata in 2 rows and upper with bulliform cells in 3 rows. Inflorescence :* Panicle lanceolate, 53·5 cm. long ; few tertiary branches at base ; spikelets arise from the base of rachae, lax ; rachis joint 7·5 mm. long ; pedicel almost equal to spikelet ; callus hairs medium dense, about thrice the spikelet ; glumes I and II light brown, sometimes with scarlet bloth above base ; glume III mediumly ciliated ; glume IV linear, ciliated along one margin, 4·1 mm. long ; anthers light yellow with pink patches, 1·8 mm. long ; stigma light purple, 1·5 mm. long.

SES. 84 B, (Plate XXVIII, Fig. 27)

Collected from : Tinnevelly-Madras ; growing on dry sands along a dry water course in gregarious patches, inside deciduous forest. *Habit : Open suberect;* stem medium thick, good tillering. *Culms : maize yellow*, heavily waxed ; internodes medium to long, 8 mm. thick ; root zone about 7 mm. wide, with 2½ staggered rows of root eyes. Bud at node, *obovate*, medium ; germpore apical ; *wing inserted on top of the prophylls*, broad with depressed apex, with very short hairs. *Epidermis with long cells having thin, straight walls alternating with cork-silica cells in pairs, and few solitary cork cells. Leaves :* Leaf sheath green with very light purple hue at base and small pink blotches ; circlet of hairs inconspicuous ; sheath base very slightly decurrent ; dewlap medium high, *triangular, oblique* ; auricle present on both sides ; ligule medium broad, *disc shaped* with a marginal fringe of short hairs. Lamina medium, reduced to midrib only at base.

SES. 85 D (Plate XXVIII, Fig. 28)

Collected from : Tinnevelly-Madras ; growing on moist sandy loam in gregarious patches along a river. *Habit : Open spreading, suberect* with few outer decumbent shoots ; stem medium thick, good tillering. *Culms maize yellow with few small red*

streaks, waxy bloom fairly heavy ; internodes medium 7 mm. thick ; root zone about 6-7 mm. wide, slightly obconoidal, with 2 staggered rows of root eyes. Bud at node, *rhomboid*, medium ; germpore subapical ; wing inserted at middle of prophyll, broad with emarginate apex, short and medium long hairs on back. *Epidermis with long cells having thin straight walls, alternating with cork-silica cells in single and multiple pairs. Leaves :* Leaf sheath green with pink hue on exposed surface, circlet of hair absent ; sheath base straight ; dewlap medium high, triangular ; short auricle on one side ; ligule medium broad, *triangular deltoid* with marginal fringe of very short hairs. Lamina medium, not completely reduced to midrib at base. *Epidermis with bulliform cells in 3 rows. Inflorescence :* Panicle broad pyramidal, 61·4 cm. long ; tertiary branches common ; spikelets arise slightly above the base of rachea, 5·6 mm. long, lax ; rachis joint 6·2 mm. long ; pedicel about half the spikelet ; callus hairs medium dense, about $2\frac{1}{2}$ times the spikelet ; glumes I and II with scarlet blotch above the coriaceous base ; glume III densely ciliated ; glume IV broad linear, densely ciliated along margins, 3·7 mm. long ; anthers yellow, 1·8 mm. long ; stigma maroon pink, 1·23 mm. long.

SES. 88 C (Plate XXVIII, Fig. 29)

Collected from : Tanjore-Madras ; growing on sandy soil along the bank of saline water canal near Point Calimere. *Habit : Close erect,* straight ; stem medium thick, good tillering. *Culms maize yellow to brownish yellow ;* heavily waxed ; internodes medium, slightly biconcave, 7 mm. thick ; root zone about 6 mm. wide, obconoidal, slightly tumescent, with $2\frac{1}{2}$ staggered rows of root eyes. Bud arises slightly above scar band, *rhomboid to oblong ovate or elliptic*, medium ; germpore apical ; wing inserted at the middle of prophyll, broad with emarginate tip, short to medium long hairs at back, apex and margins. *Epidermis with long cells having thin straight walls alternating with cork-silica cells in single and multiple pairs. Leaves :* Leaf sheath green with purple hue on exposed surface and big pink blotches ; circlet of hairs absent ; sheath base almost straight ; dewlap medium broad, triangular ; *auricle on both sides, quite prominent ; ligule broad triangular deltoid* with rounded tip and very small marginal fringe of short hairs. Lamina long, narrow, almost reduced to midrib throughout. *Lower epidermis with stomata in 2 rows and upper with bulliform cells in 3 rows.*

SES. 91 (Plate XXVIII, Fig. 30)

Collected from : Tanjore-Madras ; growing on clay soil along the margin of a waterlogged swamp by the cultivated fields. *Habit : Open erect, straight, stem thick and stout ;* good tillering. *Culms : maize yellow to light brownish yellow,* heavily waxed ; internodes medium, biconcave, 12 mm. thick, root zone about 8 mm. wide, obconoidal, tumescent, with $2\frac{1}{2}$ staggered rows of root eyes. Bud arises from root zone slightly above scarband, characteristically *obovate*, big ; germpore subapical ; wing inserted at apex, *broad with tip slightly emarginate*, short to medium long hairs on margin, apex and back. *Epidermis with long cells having thin wavy walls ; cork-silica cells in pairs. Leaves :* Leaf sheath green with deep purple hue and big pink

blothes ; fairly waxed ; circlet of hairs incomplete ; sheath base very slightly decurrent ; dewlap broad triangular ; *auricle present ; ligule broad deltoid, dome shaped*, with marginal fringe of short hairs. Lamina long and broad, reduced to midrib for about 16-18 cm. from base.

Summary

The various types of *Saccharum spontaneum* L. collected from South India show a good amount of variation in their morphology and anatomy. As regards habit, three clear forms can be recognized (1) *Erect* (2) *Suberect* and (3) *Prostrate* or *Trailing*. Other characters showing important variations are the shape and size of buds and the nature of prophylls and wings, rows of root eyes, the leaf module, hairiness on the leaf-sheath, shape of the ligule and the presence or absence of ligular process or auricle. The floral characters, which were not found so much important before, are likely to prove useful as additional characters. There is good amount of variation in the shape and size of the inflorescence, the mode of branching, the size of glume IV, and the coloration of the glumes, anther and stigma.

Stem and leaf spidermal peelings show good amount of variation in the following characters supplying important distinctive features for different types : (1) size and nature of walls of the long cells in stem epidermis ; (2) number of cork and silica cells and their mode of arrangement—whether solitary or in simple or multiple groups; (3) the nature and arrangement of the asperites or spines on the lower leaf epidermis ; (4) the number or rows of bulliform cells and the stomata in leaf epidermis ; (5) presence or absence of joint spines in the leaf epidermis.

Present observations suggest that the various types of *S. spontaneum* show intergrading range of variations, some of which have quite distinctive features. Whether these are true 'ecotypes' may be determined by future genetical experiments. This species is highly polymorphic and the variant types have been suggested to belong to the category of 'putative ecads' a category suggested by Salisbury. High plasticity within the species and ready compatibility with sugarcanes will be very useful in utilising them for evolving new types of Sugarcane by inter-breeding.

A key for identification of the 31 different types and a description with sketches of 14 promising types collected from South India and maintained under cultivation at Coimbatore Sugarcane Station are given. The schedule of characters, employed in the description of the various types, is given in the appendix.

Acknowledgements

Thanks are due to the Indian Central Sugarcane Committee for financing the Spontaneum Expedition Scheme, under which the materials were collected by the junior author while working as Assistant Botanist, Sugarcane Breeding Station, Coimbatore. We take this opportunity of acknowledging our gratitude to Shri N. L. Dutt, Sugarcane Expert, for help and constant encouragement. We also thank Prof. P. Maheshwari, Head of the Department of Botany, Delhi University, for kindly going through the manuscript and offering helpful criticism.

REFERENCES

Artschwager, E.(1925). Anatomy of the vegetative organs of Sugarcane. *J. agric. Res.*, **30**, 197-221

——— (1930) A comparative study of the stem epidermis of certain sugarcane varieties. *J. agric. Res.*, **41**, 853-865

——— (1942). A comparative analysis of the vegetative characteristics of some variants of *Saccharum Spontaneum*. *U. S. Dept. Agr., Tech. Bull.*, **811**, 1-55

Barbar, C. A.(1915). Studies in Indian Sugarcanes. 1. Punjab Canes. *Mem. Dept. Agric., Bot. Ser.*, **7**, 1-106

——— (1916). The classification of indigenous Indian canes. *Agric. J. India*, **8**, 371-76

——— (1918). Studies in Indian Sugarcanes. 3. The classification of Indian canes with special reference to the Saretha and Sunnabile groups. *Ibid.*, **9**, 133-96

——— (1919). Studies in Indian Sugarcanes. 4. Tillering on underground branching. *Ibid.*, **10**, 39-151

Bourne, B. A. (1935). A comparative study of certain morphological characters of Sugarcanes. X. Sorgo hybrids. *J. agric. Res.*, **50**, 539-552

Brandes, E. W., Sartoris, G. B., Grassl, C. O. (1939). Assembling and evaluating wild forms of sugarcane and closely related plants. *Proc. Int. Soc. Sug. Tech., VI Congr., Louisiana*, 128-53

Bremer, G. (1930). The cytology of *Saccharum*. *Proc. Int. Soc. Sug. Tech., III Congr., Socrabaia*, 408-415

Clausen, J., Keck, D. D. and Hiesey, W. M. (1945). *Experimental studies on the nature of species II. Carn. Inst. Washington, Publ.*, 564

Deerr, N. (1911). *Cane Sugar* (Norman Rodger, London)

Dutt, N. L. and Subba Rao, K. S. (1933). Observations on the cytology of the Sugarcane. *Indian J. agric. Sci.*, **3**, 37-56

Fawcett. *Sugarcane*, 220 (cited by Deerr)

Hackel, E. (1889). *Gramineae in De Candolle's Monographiae Phanerogamarum*, **6**, 113

Hadi, S. M. (1902). *The Sugar Industry of the United Provinces of Agra and Oudh*, 3-36

Harrison and Jenman. Sugarcane, 273 (cited by Deerr)

Hole, R. S. (1911). On some Indian forest grasses and their ecology. *Ind. For. Mem., For. Bot. Ser.* I., Pt. I

Hooker, J. D. (1897). *Flora of British India*, **7**, 118

Jeswiet, J. (1916). *Beschrijving dersoorten Van het suikerriet. Eerch bijdrage. Morphologie van het suikerriet. Arch. Suikerindus. Nederland. Indie.* **24**, 67-137, 359-429; 625-63

——— (1925). *Beschrijving der soorten van het suikerriet. 12 E. Bijdrage. De bloei big het geslacht Saccharum. Arch. Suikerindus. Nederland. Indie, Meded. Proefsta. Java-Suiker indus.* **33**, 405-441

Krüger (1899). *Das Zucherohr und seine Kultur*

Linnaeus, C. (1771). Mantissa Plantarum. 183

Mukherjee, S. K. (1949). *Studies on* Sacchrum spontaneum L. 1. *Preliminary report on collection. Indian J. Genet. Pl. Breed.*, **9**, 47-58

Panje, R. R. (1933). *Saccharum spontaneum* L. A. comparative study of the forms grown at the Imp. Sugarcane Breed. Station, Coimbatore. *Indian. J. agric. Sci.*, **3**, 1013-1044

Parthasarathy, N. and Subha Rao, K. S. (1946). *Chromosome survey of Saccharum spontaneum* L. *Indian J. Genet. & Pl. Breed.*, **6**, 5-10

Salisbury, E. J. (1940). *Ecological aspects of Plant Taxonomy. New Systematics*, ed. J. Huxley 329-340 (Oxford University Press, England)

APPENDIX I

Schedule of characters employed in the morphological description of types

1. *Habit of the plant and tillering*
2. *Stem characters*
   (*a*) Length of cane
   (*b*) Length of internode
   (*c*) Shape
   (*d*) Thickness
   (*e*) Colour
   (*f*) Waxy bloom and incrustations, if any
   (*g*) Markings, if any
   (*h*) Root zone
      (i) width
      (ii) number of rows of root eyes and their arrangement
   (*i*) Bud
      (i) shape
      (ii) size
      (iii) point of origin and position
      (iv) germpore-type
      (v) wings (prophyll)- their position and hairiness
   (*j*) Node: Circlet of hairs—present or absent

3. *Leaf character*
   (*a*) Leaf sheath
      (i) length
      (ii) colour and pigmentation
      (iii) waxy bloom-density
      (iv) spines or hairs at outer surface or margins-present or absent
   (*b*) Auricle or Ligular process—present or absent
   (*c*) Blade Joint
      (i) hairs at throat—length and density
      (ii) dewlap—shape, hairiness, etc.
   (*d*) Ligule
      (i) shape
      (ii) size
      (iii) pubescence—length and arrangement of hairs
   (*e*) Lamina
      (i) shape—lamina whether reduced at blade-joint to midrib or not
      (ii) size
      (iii) leaf module (ratio of breadth/length)

4. *Inflorescence*
   (*a*) Shape
   (*b*) Size
   (*c*) Nature of branching—order of branches and their arrangement
   (*d*) Rachis Joint—its length and hairiness
   (*e*) Spikelet
      (i) arrangement—close or lax
      (ii) length
      (iii) callus hairs—length and density
      (iv) *Flower*
         glume I—shape, size, colour and pubescence
         glume II—shape, size, colour and pubescence
         glume III—shape, size and pubescence
         glume IV—shape, size and pubescence
         palea—shape, size and pubescence
         lodicules—shape, size, and pubescence
         anthers—length and colour
         stigma—length and colour

CONCEPTS OF NOMENCLATURE FOR UNITS OF SOIL CLASSIFICATION

By S. P. Raychaudhuri and A. Sankaram, Indian Agricultural Research Institute, New Delhi

(Received for publication on 16 May, 1951)

Classification in simple terms is merely an arrangement or grouping of the objects based on such of their characteristics that would bring all of them into the smallest number of groups with a view to visualize the individual characteristics of the objects and study their inter-relationships. The classification groups or otherwise known as the units of classification range from one of broad generalizations to one of absolute definiteness, the object itself. The success of any system of classification is largely measured in terms of the precision with which the units are defined and named, the objects grouped under each and the universal acceptance accorded to it. The systems of classification in respect of the plant and animal kingdom, now in vogue, largely satisfy the said ideals and can, therefore, be deemed as a near approach to perfection.

Ever since soil science attained the status of an independent science, classification, on lines parallel to the biological sciences, of a large variety of soils commonly encountered, engaged the serious attention of all those interested in its study. As a first step to this end, categories of classification were worked out. The Russian scientists who primarily defined soils on the basis of the natural forces that caused soil differences established higher categories of classification, and pictured the 'Great soil groups'. Defining soils in terms of their profile characteristics the American soil scientists created the lowest category of classification *viz.*, the 'type'. In the scheme of classification the great soil group is a category of special importance to the taxonomist as it enables him to picture and remember such of the distinguishing features that categorically define and characterize them. The type besides its taxonomic significance owes its greater importance to its dual function. Firstly, a recognition of the soil types in an area is the chief object of a soil survey and secondly, the type is the unit to which all the agronomic data is related and enables extension of experimental results to other identical types. To remember the characteristics of all the recognized soil types individually and understand inter-relationships is a task of no small measure but can be achieved more satisfactorily, although in a general way, when once the inter-relationship between the type at one end and the great soil group at the other is well established. To this end, soil workers established intermediate categories between these two on scientific principles. While the great soil group at one end and the soil type at the other are recognized by their specific connotation, which are well standardized, the intermediate units, however, differ in different countries, largely in terminology and occasionally in meaning too. Some are purely taxonomic units and some cartographic, while a few others play a double role. It will be evident from a perusal of literature

on these aspects, that a marked change has taken place in the concepts of these units primarily due to their creation with varied objects in view and secondly for want of quantitative data to precisely define them. A need has, therefore, been felt to review the progressive concepts of the units of classification and state their meaning and scope of application to systems of classification obtaining in different countries. The present paper is an attempt in that direction.

Higher categories of classification. The units of classification are broadly divided into (i) Higher categories and (ii) Lower categories. The higher categories include the order, sub-order and the great soil group.

Order. The order is the highest category of classification or a broad division based on the recognized tendency of soils within a very large area to assume a general similarity as to profile owing to the dominating influence of climate and vegetation. The influence of these two genetic factors was taken as the basis to decide upon three broad divisions or 'orders' and Sibirtzev [1914] was the first to name them as Zonal, Azonal and Intra zonal. To put in the simplest terms of Baldwin *et al.* [1938] 'Zonal soils are produced under normal conditions from well drained parent material acted on by climate and biological forces'. Intra zonal soils are those in which the parent material or relief has produced an effect which over balances all other factors. Soils in which the parent material has remained just about as it was originally almost unchanged are termed 'Azonal'. The term 'normal soils' as applied by Marbut [1921] and others is a synonym for zonal soils. In a broad sense, virtually all soils are normal in relation to the summation of the factors that have caused their development. Marbut [1921] in his scheme of classification, known for its thoroughness of detail, placed emphasis on profile characteristics, more precisely eight features of the soil profile, which are necessary for the definition of the soil unit. Based on this, he broadly classified the mulitude of soil types, recognized by him during a survey of great part of the U. S. A. into two groups, since named by him'Pedocals' and 'Pedalfers'. In the scheme of classification of Baldwin *et al.* [1938] current in the U.S.A. these two groups are mentioned as the divisions of the zonal order of the soil alone.

Sub order. The sub order is a category next to the order. In the scheme of classification of Baldwin *et al.* [1938] this unit was criticized by Thorp and Smith [1949] on the grounds that in a natural system of classification the sub order has not been defined on soil characteristics alone but carries a genetic bias since it is defined in terms of climate, humidity or aridity.

Great soil group. The concept of the great soil group would appear to have been first introduced into soil literature by Prof. Hilgard in 1890 in his publication relating to a description of the broad soil groups in Mississippi and adjacent regions where the soil had been affected more by the climate than by parent material. However, it remained unrecognized till Glinka [1914] described the broad soil groups that Russian soil scientists had discovered. The great soil group is a category immediately following the sub order. Compared with the higher categories of the order, and sub order, the great soil group by virtue of the fact that it is definable by numerous and specific characteristics proved useful and fulfilled many of the

objects of classification. Despite a detailed and systematic soil classification of this nature there remain, as pointed out by Thorp and Smith [1949], some soils whose place in the great soil group is still a matter of debate. The black tropical soils of West Indies, South America and Africa and black cotton soils (*Regur*) of India are examples.

Lower categories of classification. The lower categories of classification include the family, series, type and phase.

Family. The family is a category in succession to the great soil group. Shaw [1927] defines it as a 'group of soils that are progressing towards a common or closely similar final mature condition'. More recently Baldwin *et al.* [1938] defined it as a category in classification between the series and the great soil group of soils having similar profiles composed of one or more different soil series. The officially recommended practice is to group as a family a number of series which show parallel development as to profile and which differ no more than the characters imposed by different facies of the same general kind of parent material. The Maimi family represented by Brown and Thorp [1942] is an example to this end. Milne [1940] regards this grouping as reasonable and necessary and points out that it substantially corresponds to that for which he gave the name Fasc [1934] conveying the idea of a bundle of parallel and roughly similar sticks. Marbut [1921] in his original scheme of classification considered the so called 'Immature' or 'abnormal' soils in the lower categories of family and to this end the family meant 'soils consisting of mature, its related and associated immature soils'. In the modified system of Marbut proposed by Baldwin *et al.* [1938] the so called imperfectly developed soils are placed at the great soil group and higher levels. This change meant a clear differentiation of mature and immature soils and enabled the development of a natural system of classification, for it meant the sorting with the lower units and all soils (mature) could be arranged into successively higher categories. Usually two or more geographically separated series are included in a family of soils and therefore the family is not likely to be useful in attempts to reduce cartographic detail. There is at present little published information for illustration or guidance in grouping of soil series into families beyond that of Brown and Thorp [1942] on the Maimi family. As such the limited use of this unit in schemes of soil classification should not occasion surprise.

Series. This is well known and more or less well defined unit of classification and was first introduced by Marbut [1921]. With very little modifications it is current in the American system of soil classification and is defined by Baldwin *et al.* [1938] 'as a group of soils having genetic horizons similar as to differentiating characteristics and arrangement of the soil profile, except for the texture of the surface soil and developed from a particular type of parent material'. The series is a unit of soil classification immediately following the family. A series recognizes the maximum number of fundamental characteristics of the soil profile ; hypothetically it is the largest landscape unit about which all features and properties relevant to soil formation are distinguished through a study of its profile.

Type. The soil type is the principal unit used in detailed soil researches. The definition of the type is indentical with that of series except that the texture of the

A horizon does vary significantly. Hence the texture of the A horizon is the basis for differentiating series into types. 'With the recognition of only a few of the textural classes in recent times the earlier usage of the type received modification'. With each series divided into only a few types the earlier great distinction between soil series and soil types as units of classification has largely disappeared. When only one or two types are recognized, the series and type become identical according to Riken and Smith [1949]. The unit 'type' has been very widely used in soil literature but seldom does it conform to the American definition. This may largely be ascribed to the freedom of its usage in the English language. Examples abound in literature of the wide and loose use of the term 'type' connoting fundamentally dissimilar units of classification. Basu and Sirur [1938] classified the surveyed area of Nira right bank and Pravara canal area into eight soil types and designated them as A to H. The 'series' and 'type' are identical in this instance. This nomenclature used by Basu and Sirur [*loc. cit.*] tallies more with that of Riken and Smith [*loc. cit.*] than with the textural classes according to the American definition of the unit type. This can be cited as an example of 'with each series divided into only a few types the earlier great distinction between soil series and soil types as units of classification has largely disappeared'.

Phase. The phase is a sub-division of the soil type and is defined by Baldwin *et al.* [1938] 'on the basis of the characteristics of the soil or of the landscape of which the soil is a part that are of importance in land-use but are not differentiating characteristics of the soil profile'. The importance and significance of phases is solely one of soil use, management and treatment, which is the basis of soil conservation survey.

Cartographic units. A classification of the soils on the above lines based on soil morphology would merely be of theoretical interest until a geographic expression of all the recognized soil types is given to a suitable scale on maps. Recourse has, therefore, been made to the creation of mapping units otherwise known as cartographic units. These may be defined simply as types or phases or definable only as more complex units and they include association, complex, miscellaneous land units and catena.

Association. The concept of an association, although has undergone many changes, is an outcome of the observed intimate relationship of the land and the vegetation it carries. Based on this principle it was possible to make broad delineations of the land designated as 'geographic associations', which could be represented on a small scale map. This however could not serve the purpose of soil maps designed to portray the distribution of categorically defined soil types as mere demarcations of regions uniform as to climate and vegetation signify in most cases heterogenous groups of soil characters. The soil map at one end is beset with a practical difficulty in respect of the mapping scale while the geographic association map is too general to convey the desired information about the soil. Both the difficulties could be solved by a grouping of certain soil types into an association and shown on the soil map. An association is thus defined as a group of soils with or without common characteristics geographically associated in an individual pattern [Kellogg, 1938]. It is essentially a unit of mapping and its practical application is seen in soil maps

of the U. S. A. [1938]; Japan [1948] and Scotland [1946] to mention a few. In an association irrespective of the uniformity in climate and vegetation, the heterogeneity of soils is due to the parent material differences and variations in relief. A necessary sub-division of a podsolic belt based on uniformity of the parent material gives rise to different parent material groups which are designated as 'associations'. The soils within an association are still far from uniformity due to variations in relief and the range of soils within the association are known as 'associates'. An illustration to this end is the scheme of classification of Scottish soils presented by Glentworth and Dion [1949]. Prescott [1949] adopted the term soil combination as a large mapping unit to mean a group of soil associations.

Complex. A complex is an intimate mixture of categorical units grouped into a cartographic unit. It is defined by Kellogg [1938] as a soil association composed of such an intimate mixture of areas of soil series and types or phases that they cannot be indicated separately on maps of the scale used so that the association is mapped as a unit. The complex is thus a cartographic unit but not a category of taxonomic classification.

Miscellaneous land units. In areas where no soil is present and areas of non-agricultural importance a detailed survey is not warranted and such areas specifically termed as Miscellaneous land units (formerly known as Miscellaneous land types) are mapped [Kellogg, 1937].

Catena. The term 'catena' was originally suggested by Milne [1936] to designate any soil association underlain by parent rock of uniform character—the various soils included in a catena corresponding to links in a hanging chain (the literal meaning of the term). This has been used specially by him as a cartographic unit for mapping soils of a 'difficult country' like that of East Africa. Despite this singular meaning meant by him several shades of meaning and application have been brought into the literature by soil workers. The United States workers have defined it as a group of soils within one zonal region developed from similar parent material but differing in characteristics of the solum owing to differences in relief or drainage. Thus it was meant as a genetic grouping according to relief or toposequence. Bushnell [1943] defined it as all soil series which are homologous in characteristics due to climate, time, vegetation and parent material but which differ in characteristics due chiefly to varied drainage and land form'. The American definition of the term differs fundamentally from that of what was originally meant by Milne who included within a catena all soils underlain by similar parent rock whereas the U. S. workers group together only those soils formed from similar parent material, and as such the terms catena and toposequence cannot be regarded as synonymous. Bushnell's definition of a term is at a sacrifice of the fundamental principle that a soil property is the result of an interaction of all the factors and will vary to some extent if any factor changes. It thus actually connotes the meaning that each factor independent of others imprints a set of soil properties. The members of catena may not be homologous for any soil property but will exhibit a continuous range in properties when the relief varies in continuous manner as evidenced in his own statement that soils and soil properties naturally form a continuous spectrum [Bushnell, 1943].

Greene [1946] considers the catena as defined by Milne to possess attributes of a taxonomic unit, on the basis that the material is translocated not only vertically but also laterally. As an example to this end he points out that some of the soluble salts of solonchak have been derived by seepage from an adjacent zonal soils. Brown and Thorp [1942] and Jenny [1946] emphasized that the catena concept of Bushnell and the U. S. workers is a genetic grouping inferred from field observations. Kellogg [1938] after reviewing the definitions of the term stated that catena is a particular kind of association the individual members of which may not be separable on a map. Muir [1949] has clearly brought out the relation between association and catena and showed that catena of Milne is synonymous with association of Ellis [1932]. The National Soil Survey Committee of Canada [1948] decided for the usage of the term association locally along with the term catena in parenthesis and the term catena in all publications which have international circulation, as they are synonymous for all purposes. Jenny [1946] regards that a grouping of soil series and types in terms of functions of soil forming factors has certain merits as it emphasizes a logic interlacing of soil units and is amenable to geographic expression. Accordingly of the five sequences (chronosequence, lithosequence, toposequence, clinosequence and biosequence) the toposequence was said to correspond to Milne's catena. With the published knowledge on hand the term 'sequence' is ill defined to place it either as a taxonomic or cartographic unit.

Concluding remarks. From what has been presented above it is seen that certain units of classification though differing in terminology are similar in meaning obviously due to the fact that they were the creations of different workers working in different countries to suit their specific local conditions. This can be elucidated with reference to soil surveys and soil classification adopted in the more important countries of the world (Table 1).

It is apparent at this stage that two or three intermediary categories of classification are usually recognized before the relation of a type to a great soil group is established. Textural classes of a series are universally recognized and accepted as 'Types'. The series as used in the United States is synonymous with Associates of Scotland and Manitoba and the catenary member of Canada. The term association (which includes a number of series each known as 'associate') adopted in Scotland and Manitoba are equivalent to 'Families' of the United States and Australia and 'Suite' of England. The term suite is a taxonomic unit exclusively used by Robinson [1931] during the soil survey of England and Wales.

It comes in between the series and the great soil group and thus represents a group of series derived from same or similar parent material. The soils coming under suite are divided into series according to the mode of development as reflected in the profile. As an alternative term to family, Prescott [1933] in Australia uses the term 'suite'. The term Fasc coined by Milne [1934] runs parallel to both 'suite' and 'Family'. Exceptionally, Glentworth [1944] places the term 'suite' between the associations and the great soil group and perhaps this is a singular instance of its kind. It will be clear at this stage that the grouping of series into families or suites or associations is based on the geology of the parent material and that the

TABLE 1

Units of soil classification

Country	Categories				Remarks
U. S. A.	Great soil group	Family	Series	Type	Phase (Slope, Stoniness and erosion)
Scotland	Zone	Suite or Association	Associates or *Series	Type	Phase (Depth and stony phase)
England	Great soil group	Suite	Series	Type	Phase
Australia	Zonal groups	Family or Suite	Series	Type	Phase (shallow denuded and saline)
Manitoba	Zones	Association	**Associate	Type	Phase
Canada	Zones	Sub-zones : Associations or catenas	Series, catenary member or associate	Type or class	Phase
Hawaii	Great soil group	Family	Series	Type	Phase
East Africa	Great soil group	F a s c	Series Catena	Type	Phase

*1. Oromorphic 2. Phytomorphic 3. Phyto-hydromorphic 4. Hydromorphic.
**1. Phytomorphic 2. Hydromorphic 3. Halomorphic (each of these is a series).

recognition or separation of associations or families into series or associates is one the morphology of the soil profile. Thus the creation of the units of classification is not entirely arbitrary but based on sound scientific principles. Yet their vagueness to some extent is to be ascribed to the lack of adequate quantitative data to precisely define them. Though descriptive, the units of classification are definable but the need for very precise definitions for universal adoption is urgent and imperative, if progress is aimed at in this direction.

In temperate countries soil surveys and soil classification have made more rapid marches than of the tropics, owing to the natural disabilities associated with the latter such as the vast stretches of impenetrable forest areas, threat of malaria and other deadly diseases. In recent years increased attention is being paid and the full range of problems relating to all the tropical countries were recently discussed at the first Commonwealth conference on tropical and sub-tropical soils held at Harpenden, England in June 1948. At this conference Kellogg, Hardy and Pendleton among others pointed out the difficulties for adoption of a common basis of classification of tropical soils. Opinion has been unanimous that so long as detailed soil survey of tropical soils for authoritative information on morphological, physical, chemical and mineralogical properties remain incomplete, any attempt at a classification of these soils would prove futile. With special reference to India, a major

tropical country, there has never been an all India Soil Survey although considerable number of soil surveys were carried out for a variety of purposes. Survey and classification of soils occurring in the canal zones of Bombay—Deccan have been carried out by Basu and Sirur [*loc. cit.*] and the following tabular statement explains the position of soil classification as adopted by them:

Great soil group	Family associates	Series and types	Phase
Immature tropical	(1) Oromorphic (High level shallow soils)	G, H and F	Mature and immature (or eroded)
Tschernosem	(2) Phytomorphic (low level shallow soils)	E, A, D, K and L	Mature and immature (or eroded)
	(3) Hydromorphic, Halomorphic (Deep soils, low lying)	C. I. B. and J	Normal saline

Mukherji and Das [1940] in their studies on Kumaon hill soils at Chaubatia in Uttar Pradesh found four major genetic types: forest soils, podsols, red loams, and wiesenboden. Agarwal and Mukherji [1951] in their survey of the soils of Gorakhpur district in Uttar Pradesh in the Gangetic alluvium distinguished three major soil types, depending mostly on the degree of calcium leaching in the profile. Based on a comparative studies on forty nine selected profiles of India, Viswanath and Ukil [1944] adopted colour and texture as units of classification and these in turn were treated on a background of four major climatic zones namely: arid, semi-arid, humid and per-humid.

The data are voluminous and fragmentary, being devoid of a common objective, and does not seem to be useful to frame a system of soil classification for general adoption. The units of classification and nomenclature are not the same and there is an immediate need for a uniform method of soil survey and nomenclature in soil classification work in order to understand the implications of classification work in different parts of India and to co-ordinate the work on an all India basis. So far as the existing data permitted, Indian workers attempted to place the soils studied into their respective world groups. Such an approach to the problem is no doubt accepted but that success in this direction calls for a detailed soil data on morphological, physical, chemical and mineralogical properties which cannot be too strongly emphasized.

Summary

The present communication is an attempt to review the progressive concepts of units of soil classification and to state the meaning and scope of application to systems of soil classification in different countries. The units of classification are broadly divided into (1) higher categories and (2) lower categories. The higher categories include the order, sub-order and the great soil group, whereas the lower categories include family, series, type, and phase. Cartographic units such as association, complex and miscellaneous land units are explained. The

units of soil classification adopted in different countries are given in a tabular form. Inter-relationships and limitations of the units are discussed. Soil survey work carried out in different States of India are mentioned and an immediate need is advocated for a uniform method of soil survey and nomenclature in soil classification in order to understand the implications of classification work in different parts of India and to co-ordinate the work on an all-India basis.

REFERENCES

Agarwal, R. R. and Mukherji, S. K. (1951). *Soil Sci.* **72**, 21

Anonymous (1948). *Proc. First Conf. Nat. Soil Surv. Comm. Ottawa*, Canada

Basu, J. K. and Sirur, S. (1938). *Indian J. agric. Sci.* **8**: 637

Baldwin, M., Kellogg, C. E. and Thorp, J. (1938). *U. S. D. A. Y. Book 1938, Soils and Men.* 979

Brown, I. C. and Thorp, J. (1942). *U. S. D. A. Tech. Bull.*, 834

Bushnell, T. M. (1943). *Soil Sci. Soc. Amer. Proc.* **7**; 466

Ellis, J. H. (1932). *Sci. Agric.* **12**; 338

Glentworth, R. (1944). *Trans, Roy, Soc.* (Edin.), 61; (1) 149

——————— (1949). *J. Soil. Sci.* **1** ; 35

Glinka, K. D. (1914). *Die Typen der Bodenbildung ihre Klassifikation und geographische verbreitung Verlagsbuchhandlung Gebruder Borntraeger, Berlin*

Greene, H. (1946). *Soil Sci. Soc. Amer. Proc.* **10**; 136

Jenny, H. (1946). *Soil Sci.* **61** ; 375

Kellogg, C. E. (1937). *U. S. D. A. Misc. Bull.* 274

——————— (1938). *Soil Sci. Soc. Amer. Proc.* **3**; 253

Marbut, C. F. (1921). *Soc. Prom. Agr. Sci. Proc.* **41**; 216 (quoted from a reprint of the paper in the book *Life and work of Marbut*-Art Craft Press)

Milne, G. (1935). *Soil Res.* **4** ; 183

——— (1940). *East African Agr. Res. Station*, Amani Govt. Press, 78

Muir, A. (1949). *Sci. Hort.* **9**; 15

Mukherji, B. K. and Das, N. K. (1940). *Indian J. Agric. Sci.* **10** ; 990

Prescott, J. A. (1933). *Emp. J. Exptl. Agrl.* **1** ; 333

Riken, F. F. and Smith, G. D. (1949). *Soil Sci.* **67**; 107

Robinson, G. W. (1931). *J. Minist. Agric.* **38**; 379

——————— (1949). *Soils, their origin, constitution and classification. Thomas Murdy & Co. Ltd.*,

Shaw, C. F. (1927). *First Internat. Cong. Soil Sci. Comm. V & VI*: **38**

Sibrtzev, N. M. (1914). Quoted from Robinson (1931)

Thorp, J. and Smith, G. D. (1949). *Soil Sci.* **67** ; 117

Viswanath, B. and Ukil, A. C. (1944). *Indian J. Agric. Sci.* **14**; 333

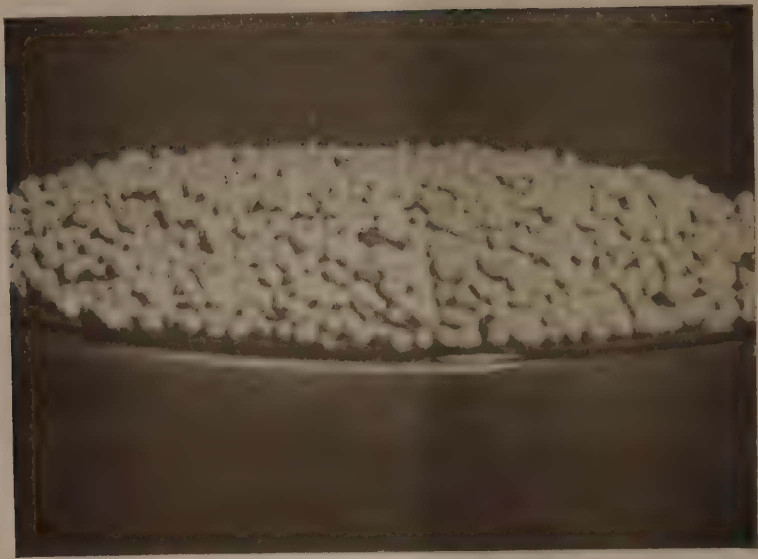


Fig. 1. Small castings

Fig. 2. Large castings

PHYSICO-CHEMICAL PROPERTIES OF EARTHWORM CASTINGS AND THEIR EFFECT ON THE PRODUCTIVITY OF SOIL

By S. D. Nijhawan, Agricultural Chemist, Punjab and J. S. Kanwar,

Lecturer in Chemistry, Government Agricultural College, Ludhiana, Punjab

(Received for publication on 5 September 1951)

(With Plates XXIX—XXX)

THE important role that earthworms play in affecting the physico-chemical properties of the soil is a very fascinating subject. Their activity has interested scientists of all ages but perhaps the first scientific approach to the study of earthworms' activities was made by Darwin in the 19th century. Since his time greater and greater attention has been paid to the subject, specially in the last decade of the present century.

The earthworms digest large amounts of soil and deposit their castings (excretions) in their burrows or on the surface of the soil. In the Punjab two types of earthworm castings (Plate XXIX, Figs. 1 and 2) are met with, the small castings and the large castings. These are excretions of two different species of earthworms. The small ones (Plate XXIX, Fig. 1) consist of spherical balls or pellets lying in heaps discretely near the surface of the soil in the burrows or near the root-zones of the plants. These were recognized by Bahl [1947] to be excretions of *Pheretima*-Sp.—a confirmed burrower. The large castings (Plate XXIX, Fig. 2) consist of large tower-like structures with one central channel. They are very conspicuous and are found in abundance during rainy season. They are deposited by *Euthyphoeus waltoni*—the common rain worm which is surface feeder and deposits its castings on the surface of the soil.

The chemical composition of earthworm castings probably of large type has been reported by many investigators like Wollny [1890] Puh [1941] Lunt and Jacobson [1944] Shrikhande and Pathak [1948] but no information is available regarding their physical characteristics. Chemical characteristics of the second type of castings i.e., small castings, have not been reported by any investigator so far. In this paper it is intended to discuss the physico-chemical properties of both the types of earthworm castings, collected from the different climatic zones of the Punjab and their effect on the productivity of the soil.

Collection of material

Soil and earthworm casting samples were collected from different climatic zones of the Punjab State, details of which are given below:

Serial No.	Place	Climatic zone with rainfall.	No. of samples	Nature of castings	Number of soil samples
1	Bhakra (cultivated fields)	Mountains 55-60 in. rainfall	4	large	4(0—9 in.)
2	Khera, Hoshiarpur (cultivated fields)	Submontane 40·0 in. rainfall	4	large	4(0—9 in.)
3	Kitna, Hoshiarpur (cultivated fields)	Submontane 35·0 in. rainfall.	4	small	4(0—9 in.)
4	Ludhiana field E (mango basins)	Plains 25.6 in.	4	large	4(0—6 in.) 4(6—9 in.) 4(9—18 in.)
5	Ludhiana field A (cultivated field)	Do.	4	small	4(0—6 in.) 4 (6—9 in.) 4 (9—18 in.)

I. *Physical characteristics of earthworm castings*

Mechanical composition of castings. In Table I are given the results of mechanical analysis of above mentioned samples. The analysis was done by the international pipette method.

TABLE I

Mechanical analysis of castings and soils

Description of samples	Percentage on air dry basis			
	Coarse sand	Fine sand	Silt	Clay
Large castings Ludhiana	39·77	32·40	14·14	8·86
Parent soil do. (0—6 in.)	32·03	37·64	11·74	15·80
Parent soil do. (6—9 in.)	48·64	33·16	7·79	7·0
Parent soil do. (9—18 in.)	39·44	32·33	10·02	5·96
Large castings Khera (Hoshiarpur)	38·90	26·82	20·41	10·11
Parent soil do. (0—9 in.)	28·80	31·30	28·50	12·90
Large castings Bhakra	31·00	43·30	20·40	5·30
Parent soil do. (0—9 in.)	17·27	43·60	27·60	11·50
Small castings (Ludhiana)	45·20	38·00	7·50	7·92
Parent soil do. (0—6 in.)	38·70	39·64	8·02	10·00
Parent soil do. (6—9 in.)	36·70	35·80	3·00	23·50
Parent soil do. (9—18 in.)	31·94	41·44	14·50	9·32
Small castings Kitna (Hoshiarpur)	26·65	43·99	17·81	7·20
Parent soil (0·9 in.)	16·82	44·49	21·45	13·31

These results show that both the types of earthworm castings irrespective of locality contained more of coarser fractions, i.e., coarse sand, and less of finer soil separates than the parent soil. It seems that earthworms by their activities increase the amount of coarser fractions in their castings, retaining more of the finer fractions and rejecting the coarser particles out of the swallowed soil. This behaviour of earthworms seems to be common to both the types of earthworms. Lindquist [1942] found that earthworms by their activities increase the content of coarse and medium sand while Evans [1948] on the contrary noted that the earthworms increased the amount of fine fractions in the soil. However, both the workers have not mentioned how this change in the mechanical composition of the soil is brought about by the earthworms.

Dispersion coefficient

The dispersion coefficient of the different castings and soil samples was determined after soaking 20 gm. of material for different periods and the results are given below :

TABLE II

Dispersion coefficient of castings and soil samples

Description of samples	Dispersion coefficient after				
	15 minutes	One hour	4 hours	12 hours	24 hours
1. Large castings Ludhiana	5·88	11·80	2·86	1·58	1·13
2. Parent soil	9·80	18·90	9·30	9·20	6·35
3. Large castings *Bhakra*	12·40	16·80	3·01	1·89	1·60
4. Large castings *Khera* (Hoshiarpur)	4·82	8·35	6·89	2·01	1·49
5. Small castings Ludhiana	1·82	4·95	3·4	1·46	1·28
6. Parent soil (0—9 in.)	11·50	16·50	7·10	2·70	1·20
7. Small castings *Kitna* (Hoshiarpur)	12·40	21·60	13·90	2·65	1·55

These results show that dispersion coefficient of the castings was less than the corresponding parent soil. Dispersion coefficient increased with time and it was maximum after one hour soaking and after that it began to decrease. This is supported by the results of aggregate analysis. The decrease in dispersion coefficient after one hour soaking was also noticed by Nijhawan *et al.* [1947] while finding dispersion coefficients of soil aggregates. How this occurs, requires further investigation ; probably this may be explained by the dipolar theory of Russel [1934].

Rate of percolation

Rate of percolation through both types of castings and the soil was compared in duplicates. Hundred grams of material were added in the percolation tubes and the uniform packing was ensured by tapping the tubes twenty times gently against the hand. The head of water in every tube was kept constant by a T. Tube arrangement connected with an aspirator bottle. Percolate was collected and measured after every hour. These experiments were repeated four times and average figures are reproduced in Table III.

TABLE III

Rates of percolation (M. L. per hour)

Hours	Small castings	Large castings	Soil
1st	291·0	17·0	38·5
2nd	215·0	14·0	38·5
3rd	90·0	9·0	27·5
4th	80·0	5·5	19·0
5th	75·0	5·5	15·0
6th	61·0	4·5	11·0
7th	51·0	4·3	9·5
8th	37·5	4·2	8·5
Average	112·5	8·2	20·9
Second 8 hours			
1st	35·0	3·5	13·0
2nd	34·1	3·5	13·0
3rd	33·5	3·5	11·5
4th	32·5	3·5	9·5
5th	32·0	3·5	4·8
6th	31·5	3·3	4·6
7th	29·5	3·3	4·4
8th	28·0	3·1	4·1
Average per hour	32·01	3·4	8·2
Third 8 hours			
1st	27·0	3·0	4·3
2nd	26·5	3·0	4·0
3rd	26·5	2·7	4·2
4th	26·5	2·4	4·2
5th	24·0	2·4	3·9
6th	22·5	2·5	3·7
7th	21·0	2·5	3·5
8th	16·0	2·2	3·4
Average	20·4	2·6	3·9

These results show that small castings have higher rate of percolation than the large ones and the soil. The large ones are inferior to the soil in this respect. The decrease in the volume of the castings and the soil was found to be 6·45, 39·8 and 0·65 per cent in the case of small castings, large castings, and the soil respectively. Decrease in volume indicates that the size of pores greatly decreased in the large castings as compared to small castings and the soil after submerging under water and this affected the rate of percolation.

Amount of water stable aggregates in earthworm castings and soil

The water stable aggregates in earthworm castings and the soil samples of the same site were determined by the Yoder's wet sieving technique. The bank of sieves consisted of sieves of 5, 3, 2, 1, 0·5 and 0·2 mm. meshes. Hundred grams of material were used for each determination. Pre-wetting was found to be quite essential in case of earthworm castings also, as it was noted to be in case of soil samples by Nijhawan and Olmstead [1947]. Primary unaggregated particles were separated from the silt and clay aggregated particles by the dispersion of

the collection in each sieve with NaOH after boiling with acidified H_2O_2 to oxidise organic matter. The dispersed material was again sieved in water. Thus the primary unaggregated particles were collected on different sieves and weighed. The amount of coarse sand in aggregates was also determined by sieving the dispersed material through 0·2 mm. sieves. The results are given in Table IV.

Table IV

Distribution of water stable aggregates of different sizes in earthworm castings

Description of samples	Nature of aggregates		Percentage of aggregates of diffrent sizes					
			5 mm	3-5 mm	2-3 mm	1-2 mm	0·5 mm	0·2-0·5 mm
Large castings Ludhiana	*(a) Total	77·01	6·73	5·05	2·13	12·97	6·37	43·76
	*(b) True	72·24	6·73	5·05	2·13	8·20	6·37	43·76
	*(c) Minimum	49·97	4·52	3·34	0·23	7·00	4·50	29·38
Ludhiana soil of large castings site	(a) Total	52·74	..	3·90	4·72	3·83	4·75	35·54
	(b) True	52·18	..	3·90	4·72	3·83	4·75	35·54
	(c) Minimum	17·63	..	2·49	2·91	2·52	2·84	6·87
Large castings Bhakra	(a) Total	85·77	69·40	3·70	1·50	1·25	7·72	2·20
	(b) True	81·23	69·40	3·70	1·50	1·25	3·18	2·20
	(c) Minimum	44·00	35·80	1·30	1·20	1·00	2·90	1·80
Large castings Khera (Hoshiarpur)	(a) Total	90·27	73·93	2·41	2·16	1·38	7·99	2·40
	(b) True	86·81	73·93	2·41	2·16	1·38	4·53	2·40
	(c) Minimum	55·87	46·21	1·50	1·34	0·87	3·81	2·14
Small castings Ludhiana, July	(a) Total	58·23	..	0·49	5·51	2·96	28·48	20·79
	(b) True	38·22	..	0·41	5·08	2·88	9·06	20·79
	(c) Minimum	17·50	..	0·05	3·12	1·78	8·09	4·46
Small castings Ludhiana, November	(a) Total	64·78	..	3·68	8·94	9·60	26·93	15·68
	(b) True	58·31	..	2·76	7·81	9·24	22·32	15·68
	(c) Minimum	39·32	..	1·75	5·54	6·79	20·92	4·32
Soil of above small castings site Ludhiana	(a) Total	36·59	..	..	0·81	0·06	30·96	4·76
	(b) True	36·59	..	..	0·81	0·06	30·96	4·76
	(c) Minimum	5·75	..	..	0·65	0·02	0·60	4·48
Small castings Kitna, Hoshiarpur	(a) Total	65·89	..	0·63	13·76	14·24	27.09	10·17
	(b) True	62·44	..	0·63	13·76	14·24	23·64	10·17
	(c) Minimum	40·39	..	0·30	9·99	11·04	13·61	5·45

*(a) Total aggreagtes of different sizes = The residue after first sieving through water

(a_1) Primary unaggregated particles of size bigger than the mesh of the sieve. = The residue retained on a particular sieve after treatment with H_2O_2, acetic acid and dispersion with NaOH

*(b) True aggregates = (a—a_1)

*(c) Minimum amount of aggregates = True aggregates-coarse sand.

These results show that earthworm castings had higher amount of water stable aggregates than the soil, secondly the large castings had more total aggregates than the small castings and thirdly the amount of 2 to 3 and 1 to 2 mm. sized aggregates was higher in small castings than the large ones and the soil. The aggregates bigger than 3 mm. in diameter were more in large castings than the small castings.

Many investigators such as Dutt [1948], Dawson [1948] and Hopp [1946] found that by their activities earthworms increase the amount of water stable aggregates in the soil. However, they have not specifically mentioned the cause but it is highly probable that the high amount of water stable aggregates in the soil replete with earthworms is mainly due to high amount of castings deposited by the earthworms in the soil. These castings have very high amount of water stable aggregates, as is borne out by the results presented above. High earthworm activity in a soil means increased production of castings which is synonymous with large amount of water stable aggregates in the soil.

II. *Chemical Composition of earthworm castings*

In Table V are given the results of organic matter, total nitrogen, nitrate nitrogen and C/N ratio of earthworm castings.

TABLE V

Chemical characteristics

Description of samples	Organic matter	Total nitrogen	Nitrate nitrogen (MGS)	C/N ratio
	(Percentage on air dry material)			
1. Large castings, Ludhiana	1·72	0·12	4·34	8·3
Parent soil (0—6 in.)	1·49	0·09	1·22	10·8
Parent soil (6—9 in.)	1·24	0·04	..	17·0
Parent soil (9—18 in.)	0·60	0·04	..	8·9
2. Large castings, Khera (Hoshiarpur)	2·40	0·15	2·93	8·8
Parent soil (0—9 in.)	1·96	0·05	2·70	21·8
3. Large castings, Bhakra	3·02	0·16	0·80	10·4
Parent soil (0—9 in.)	2·32	0·12	0·72	11·0
4. Small castings, Ludhiana	0·74	0·05	0·37	8·8
Parent soil (0—6 in.)	0·60	0·04	0·33	8·7
Parent soil (6—9 in.)	0·45	0·04	..	6·3
Parent soil (9—18 in.)	0·45	0·04	..	6·3
5. Small castings, Ludhiana	0·73	0·07	0·28	5·9
Parent soil (0—6 in.)	0·60	0·05	..	7·0
Parent soil (6—9 in.)	0·56	0·05	..	8·1
Parent soil (9—18 in.)	0·27	0·04	..	5·3
6. Small castings, Kitna (Hoshiarpur)	1·48	0·12	11·69	7·7
Parent soil do. (0—9 in.)	1·29	0·09	5·65	8·8

The results indicate that earthworm castings irrespective of type and locality had more of organic matter, total nitrogen and nitrate nitrogen than the parent soil. The large castings had more of these nutrients than the small ones and also more than parent soil. Both the types of castings had lower C/N ratio than the

parent soil. This clearly shows that the earthworm castings contain not only higher amount of organic matter but proportionately much higher amount of nitrogen as compared with the soil. The higher amount of organic matter and nitrogen in large castings as compared to the small castings is due to the difference in the feeding habits of earthworms, whose excretions they are. The large castings producing species being mainly surface feeders produce castings with more organic matter as compared to small casting producing species because the surface soil is always richer in organic matter than the lower layers.

Mineral content

Mineral content of castings and soil samples is given in Table VI. From the results it will be observed that calcium carbonate and calcium in both the types of castings was more than the parent soil. Large castings as compared to small ones contained much more of these constituents. This is due to the presence of well developed calciferous glands in the *Eutyphoeus waltoni* sp. of earthworm which produce large castings. These glands are responsible for excretion of calcium and calcium carbonate in the form of castings. Whereas in *Pheretima* sp. which produce small castings these glands are rudimentary and hence there is lower amount of this ingredient in small castings. If the soil does not contain calcium carobnate, in that case the large castings formed in such soils also do not contain calcium carbonate as will be seen from the analysis of large castings collected from Bhakra soil—a soil developed under high rainfall and having no free calcium carbonate. These results lend support to the observation of Stephenson and Parishad [1919] who maintain that the function of calciferous glands is excretion of calcite particles and not secretion.

Phosphorus (total and available) potassium, manganese, exchangeable metal cations such as Ca, Mg, K, Na are more in large castings than in the small ones, which had even less of these constituents than the parent soil. The differences in the amount of mineral constituents of the small and the large castings can be attributed to differences in organic matter content. Large castings having more of organic matter contain more of such minerals whereas the small ones, though richer in organic matter and phosphorous (available and exchangeable) contain far less amounts of other nutrients like exchangeable calcium, total calcium and total phosphorous than the parent soil. These results show that the mineral content of the large castings is many times higher than the small ones and the soil as well, whereas the small castings are in many respects poorer than the soil. The composition of the large castings confirms the observations of Puh [1941], Lunt and Jacobson [1944], Shrikhande and Pathak [1948] who seem to have analysed the large castings, though they did not mention the nature of the castings.

p*H Value.* pH value was determined by glass electrode, the results are given in Table VII.

These results show that the earthworm castings of all localities had lower pH value than the parent soils, which were either alkaline or neutral. The lower pH value of castings as compared with the parent soils studied in this investigation are

TABLE VI

Chemical composition of earthworm castings.

Constituent	Large casting Ludhiana	0—6 in. soil	6—9 in. soil	9—18 in. soil	Large casting Khera	0—9 in. soil	Large casting Bhakra	0—9 in. soil	Small casting Ludhiana	0—6 in. soil	6—9 in. soil	Small casting Ludhiana	0—6 in. soil	6—9 in. soil	9—18 in. soil	Small casting Kitna	0—9 in. soil
$CaCO_3$	4·71	1·9	1·3	0·5	4·6	1·8	..	..	0·7	0·5	6·2	0·9	0·6	..	0·1	5·6	5·1
HCl Soluble constituents																	
Fe_2O_3	2·50	1·63	1·52	1·83	1·96	1·70	2·03	3·18	1·6	1·72	2·15	1·60	1·65	1·45	1·48	2·88	2·20
P_2O_5	0·146	0·133	0·121	0·102	0·205	0·185	0·144	0·077	0·080	0·097	0·10	0·108	0·138	0·114	0·112	0·197	0·241
Al_2O_3—TiO_2	2·86	4·02	2·80	3·51	4·10	2·67	4·68	3·79	1·25	5·44	8·75	2·73	2·72	3·47	5·55	2·96	4·71
CaO	2·67	1·94	2·24	0·99	2·42	1·10	0·52	0·42	0·66	0·78	0·58	0·74	0·58	0·46	0·58	2·86	2·83
MgO	0·71	1·08	0·69	0·72	1·47	0·86	0·31	0·23	0·63	0·72	0·72	0·80	0·81	1·09	0·90	1·09	0·89
K_2O	0·575	0·448	0·484	0·49	0·639	0·534	0·540	0·361	0·889	0·470	0·461	0·387	0·510	0·503	0·534	0·705	0·618
Mn_3O_4	0·0435	0·0528	0·034	0·020	0·032	0·0128	0·0560	·047	0·0439	0·510	0·034	0·070	0·040	0·040	0·0460	0·0834	0·0435
Exchangeable bases																	
Calcium M. E.	6·5	6·7	5·3	5·3	6·5	5·3	11·8	9·5	2·6	9·8	10·0	3·6	9·8	5·0	5·3	5·3	7·66
Magnesium ,,	3·4	3·1	3·9	4·1	4·4	2·9	3·8	0·32	2·5	3·96	4·05	2·39	4·05	3·88	3·96	4·2	5·06
Potassium ,,	0·92	1·13	1·07	0·95	1·92	2·1	0·72	0·87	0·59	0·85	0·37	1·0	0·18	1·50	0·12	1·53	0·92
Sodium ,,	0·42	0·03	0·02	0·01	0·35	0·28	0·31	0·41	0·30	0·24	0·24	0·11	0·44	2·43	1·61	0·59	1·42
Total Exchangeable cations	11·24	10·96	10·29	10·36	13·17	10·58	16·63	11·10	5·99	0·85	14·66	7·10	14·47	9·81	10·99	11·62	15·06
Total divalent cations	9·9	9·8	9·2	9·4	10·9	8·2	15·6	9·82	5·1	13·76	14·05	5·99	13·85	8·88	9·26	9·5	12·72
Available P_2O_5 mg. per cent	9·3	6·2	3·5	3·6	22·9	13·5	4·8	1·1	4·5	7·1	5·4	8·0	8·0	3·8	2·4	29·3	27·0
Exchangeable P_2O_5 (mg. per cent)	4·8	2·2	1·58	1·76	5·26	1·66	5·00	4·26	9·71	1·81	1·84	9·81	8·93	2·500	1·611	8·690	26·3

indicative of the beneficial effects of earthworms in decreasing the—pH value of the alkaline soils. These results corroborate the findings of Puh [1941] Lunt *et al.* [1944] but are at variance with those of Shrikhande *et al.* [1948].

TABLE VII

pH value of castings and soils

Description of samples	pH value	Description of samples	pH value
Large castings Ludhiana	7·22	Small castings Ludhiana	7·95
Parent soil (0—6 in.) Ludhiana	7·65	Parent soil (0—6 in.) Ludhiana	8·00
Parent soil (6—9 in.) Ludhiana	7·83	Parent soil (6—9 in.) Ludhiana	8·02
Parent soil (9—18 in.) Ludhiana	7·98	Parent soil (9—18 in.) Ludhiana	7·90
Large castings, Khera	7·55	Small castings Hoshiarpur (Kitna)	7·58
Parent soil (0—9 in.) Khera	8·0	Parent soil (0—9 in.) Hoshiarpur (Kitna)	7·88
Large castings, Bhakra	7·50		
Parent soil (0—9 in.) Bhakra	8·00		

III. *Effect of climate on the composition of earthworm castings*

Climate exercises a very profound influence on the nature and properties of soil. In order to find out how the soils developed under different climatic conditions effected the nature of the earthworm castings, the casting samples were collected from places receiving different amounts of rainfall, a most important single factor determining the climate. Some outstanding differences indicative of the effect of climate are represented in Table VIII.

TABLE VIII

Chemical characteristics of the castings collected from different places

Description of samples	Rainfall inches	pH value	Percentage of organic matter	Percentage of total nitrogen	C/N ratio	Percentage of $CaCO_3$	Percentage of total calcium	Exchangeable Ca. ME.	Percentage of Al_2O_3
Large castings									
1. Ludhiana plains, November	25·6	7·91	1·72	0·12	8·3	4·7	2·17	6·5	2·85
2. Submontane, Khera (Hoshiarpur)	40·0	7·55	2·40	0·15	8·8	4·63	2·41	6·5	4·09
3. Montane Bhakra	55·60	7·50	3·02	0·16	10·4	..	6·52	11·8	4·68
Small castings									
1. Plains Ludhiana	25·6	7·9	0·73	0·07	6·04	0·90	0·74	3·6	2·73
2. Submontane Kitna (Hoshiarpur)	35·0	7·58	1·48	0·12	7·0	5·35	2·86	5·8	2·06

TABLE VI

Chemical composition of earthworm castings.

Large casting Khera	0—9 in. soil	Large casting Bhakra	0—9 in. soil	Small casting Ludhiana	0—6 in. soil	6—9 in. soil	Small casting Ludhiana	0—6 in. soil	6—9 in. soil	9—18 in. soil	Small casting Kitna	0—9 in. soil
4·6	1·3	..	..	0·7	0·5	6·2	0·9	0·6	..	0·1	5·6	5·1
1·96	1·70	2·03	3·18	1·6	1·72	2·15	1·60	1·65	1·45	1·48	2·88	2·20
0·205	0·185	0·144	0·077	0·080	0·097	0·10	0·108	0·138	0·114	0·112	0·197	0·241
4·10	2·67	4·68	3·79	1·25	5·44	8·75	2·73	2·72	3·47	5·55	2·96	4·71
2·42	1·10	0·52	0·42	0·66	0·78	0·58	0·74	0·58	0·46	0·58	2·86	2·83
1·47	0·86	0·31	0·23	0·63	0·72	0·72	0·80	0·81	1·09	0·90	1·09	0·89
0·639	0·534	0·540	0·361	0·889	0·470	0·461	0·387	0·510	0·503	0·534	0·705	0·618
0·032	0·0128	0·0560	·047	0·0439	0·510	0·034	0·070	0·040	0·040	0·0460	0·0834	0·0435
6·5	5·3	11·8	9·5	2·6	9·8	10·0	3·6	9·8	5·0	5·3	5·3	7·66
4·4	2·9	3·8	0·32	2·5	3·96	4·05	2·39	4·05	3·88	3·96	4·2	5·06
1·92	2·1	0·72	0·87	0·59	0·85	0·37	1·0	0·18	1·50	0·12	1·53	0·92
0·35	0·28	0·31	0·41	0·30	0·24	0·24	0·11	0·44	2·43	1·61	0·59	1·42
13·17	10·58	16·63	11·10	5·99	0·85	14·66	7·10	14·47	9·81	10·99	11·62	15·06
10·9	8·2	15·6	9·82	5·1	13·76	14·05	5·99	13·85	8·88	9·26	9·5	12·72
22·9	13·5	4·8	1·1	4·5	7·1	5·4	8·0	8·0	3·8	2·4	29·3	27·0
5·26	1·66	5·00	4·26	9·71	1·81	1·84	9·81	8·93	2·500	1·611	8·690	26·3

indicative of the beneficial effects of earthworms in decreasing the—*p*H value of the alkaline soils. These results corroborate the findings of Puh [1941] Lunt *et al.* [1944] but are at variance with those of Shrikhande *et al.* [1948].

TABLE VII

*p*H *value of castings and soils*

Description of samples	*p*H value	Description of samples	*p*H value
Large castings Ludhiana	7·22	Small castings Ludhiana	7·95
Parent soil (0—6 in.) Ludhiana	7·65	Parent soil (0—6 in.) Ludhiana	8·00
Parent soil (6—9 in.) Ludhiana	7·83	Parent soil (6—9 in.) Ludhiana	8·02
Parent soil (9—18 in.) Ludhiana	7·98	Parent soil (9—18 in.) Ludhiana	7·90
Large castings, Khera	7·55	Small castings Hoshiarpur (Kitna)	7·58
Parent soil (0—9 in.) Khera	8·0	Parent soil (0—9 in.) Hoshiarpur (Kitna)	7·88
Large castings, Bhakra	7·50		
Parent soil (0—9 in.) Bhakra	8·00		

III. *Effect of climate on the composition of earthworm castings*

Climate exercises a very profound influence on the nature and properties of soil. In order to find out how the soils developed under different climatic conditions effected the nature of the earthworm castings, the casting samples were collected from places receiving different amounts of rainfall, a most important single factor determining the climate. Some outstanding differences indicative of the effect of climate are represented in Table VIII.

TABLE VIII

Chemical characteristics of the castings collected from different places

Description of samples	Rainfall inches	*p*H value	Percentage of organic matter	Percentage of total nitrogen	C/N ratio	Percentage of $CaCO_3$	Percentage of total calcium	Exchangeable Ca. ME.	Percentage of Al_2O_3
Large castings									
1. Ludhiana plains, November	25·6	7·91	1·72	0·12	8·3	4·7	2·17	6·5	2·85
2. Submontane, Khera (Hoshiarpur)	40·0	7·55	2·40	0·15	8·8	4·63	2·41	6·5	4·09
3. Montane Bhakra	55·60	7·50	3·02	0·16	10·4	..	6·52	11·8	4·68
Small castings									
1. Plains Ludhiana	25·6	7·9	0·73	0·07	6·04	0·90	0·74	3·6	2·73
2. Submontane Kitna (Hoshiarpur)	35·0	7·58	1·48	0·12	7·0	5·35	2·86	5·8	2·96

A perusal of the above data shows that organic matter, total nitrogen, C/N ratio, exchangeable calcium and aluminium oxide increased with the increase in rainfall whereas calcium carbonate, total calcium and *p*H value decreased exception being Hoshiarpur sample of small castings. A similar behaviour was noted by Jenny [1930 and 1941] in case of soil. It shows that earthworm castings are affected by rainfall, similarly, as the soil, or the variations in the composition of soil affected by climatic factors are manifested in the earthworm castings. The other constituents (Table VI) did not show any uniform variation with the rainfall.

Effect of earthworm castings on the productivity of soil

From Darwin's times many investigators have conducted experiments to study the role that earthworms can play in increasing the productivity of the soil. The main technique has been to add living and dead earthworms to the soil and study their effect on the yield of crops. Results so far obtained are conflicting and no definite answers have been received to the following two important questions :

(*a*) Do the earthworms increase the productivity of the soil ?

(*b*) If so how do they increase it ?

As regards the first question there are clearly two schools of thought, one represented by Wollny [1890], Russel [1909], Archangelski [1929], Hopp and Slater [1948] who maintain that earthworms do increase the yields but the increase varies with the nature of the soil and crops, and the other led by Chadwick *et al.* [1948], Bates [1933] and Froud [1948] who maintain that high yields got from the fields containing large number of earthworms cannot be aptly attributed to them or to their activities but to the biotic factors like high moisture and organic matter content of the soil which are essential for erathworms also favour crops.

The second question that how they bring about increase in yields is also much disputed. There can be four ways by which earthworms may increase the productivity.

(*a*) By the decomposition of their bodies nutrients are released which increase crop yields. This has the support of Russel [1910] Hopp and Slater [1948] who found that the addition of dead earthworms resulted in increased yields.

(*b*) Living earthworms decompose organic matter quickly and increase nitrification which becomes responsible for increased yields. Russel [1910] observed that the decomposition of organic matter and nitrification was not significantly accelerated by earthworms, whereas Hopp *et al.* [1948] observed that nitrification was markedly increased by them.

(*c*) The earthworms improve the physical conditions of the soil. Their chief work is to act as cultivators, loosening and mulching the soil, facilitating drainage

FIG. 1. Showing the effect of different types of castings on wheat growth

I. Soil alone
II. Large castings
III. Small castings

FIG. 2. Showing the effect of mixing small castings with soil on wheat growth

I. E—Soil alone
II. A—10 per cent concentration of castings throughout
III. B—20 per cent ,, ,, ,, ,,
IV. C—10 per cent ,, only in the upper 4 in.
V. D—20 per cent ,, ,, ,, ,, ,,

and aeration by their burrows. Thus the improved soil structure may be partially or wholly responsible for increasing yields. There is consensus of opinion of the investigators like Wollny [1890], Russel [1909], Hopp and Slater [1948] on this point. However, the extent to which the burrowing activities of earthworms can contribute to increased yields has not been determined so far.

(*d*) The fourth possibility is that their castings which have been reported by many investigators to be rich in plant nutrients may be responsible for increasing crop outturns. However, this aspect of the question has not received any attention and it is not known how and to what extent the addition of the castings to the soil brings about increase in the yields. Since the excretions of earthworms are one of their chief contributions to the soil, therefore their effect on the productivity of soil was investigated and the results obtained are being discussed below :

Experimental

To study the effect of earthworm castings on the productivity of soil, a number of experiments were conducted under controlled conditions and their effect on the growth and the yield of wheat crop recorded.

Experiment No. 1

Comparative productivity of different types of earthworm castings and the soil

Treatments

A. 2 lb. small castings (Ludhiana samples)

B. 2 lb. large castings (Ludhiana samples)

C. 2 lb. soil of Ludhiana small castings site

Growth studies

The growth rate of wheat plants in small castings was more than double as compared to large castings and the soil in the first two months. The large castings and the soil within themselves showed no differences in the initial stages, but from February onwards the growth rate in wheat plants sown in large castings was much higher than others (Plate XXX, fig. 1). At the time of harvesting the average height was 53·3, 54·9 and 42·5 cm. in case of small castings, large castings and the soil respectively. Maximum tillering had occurred by February when tillers in plants grown in small castings and large castings were 332·9 per cent and 142·8 per cent respectively as compared to tillers in plants sown in soil taken as hundred. Similarly average number of leaves per plant was 12·2, 8·2 and 7·8 in small castings, large castings and soil respectively. Earing of the plants in small castings was earlier than in others by about three weeks. Average ear length at harvest was 5·9, 5·6 and 4·0 cm. in small castings, large castings and soils respectively.

TABLE IX

Yield data

	Small castings (A)		Large castings (B)		Soil (C)	
Total dry matter (Grams per pot)	4·47 4·89 4·04	4·46	3·64 3·27 4·02	3·64	1·77 1·39 1·59	1·58
Grain yield (Grams per pot)	2·19 2·19 1·59	1·99	1·04 1·15 0·93	1·04	0·39 0·50 0·39	0·426
No. of grains (Grains per pot)	59 64 40	54·3	46 45 45	45·3	23 19 17	19·6

These results show that both types of castings yielded more of total dry matter, grain and number of grains than the soil and small castings were more productive than the large castings.

EXPERIMENT 2

Effect of different doses of the small castings and their mode of application on the productivity of soil

In this experiment only small castings (Ludhiana samples) were used. Two concentrations ten and twenty per cent and two methods of application mixing with the upper 4 in. of soil and mixing with the entire one foot column of soil in pots were used. Each pot contained 20 lb. of material. The experiment was triplicated and the details of the treatments are given below :

Treatments	Amount of castings	Concentration of castings	Mode of application
A.	2 lb.	10 per cent	Mixed with the entire 1 ft. column of soil making a uniform concentration 10 per cent throughout
B.	4 lb.	20 per cent	Mixed with the entire 1 ft. column of soil making a uniform concentration 20 per cent throughout
C.	1 lb.	10 per cent	Mixed with the upper 4 in. making 10 per cent concentration in upper layer only
D.	2 lb.	20 per cent	Mixed with the upper 4 in. making 10 per cent concentration in upper layer only
E.	*nil*	*nil*	soil alone

Growth studies

TABLE X

Growth data

(Showing maximum shoot length, average number of tillers, leaves and ear length per plant)

	A	B	C	D	E
Maximum average shoot length	61·3	64·0	58·9	62·3	56·6 (cm.)
Ear length	6·9	7·8	6·4	7·5	5·8 (cm).
Average number of tillers	2·9	2·9	1·9	2·5	1·8
Average number of leaves	12·5	13·3	10·8	11·3	6·3

The data presented in Table X show that maximum growth occurred in treatment B and minimum in E (Plate XXX, Fig. 2) D and A both showed better growth than C but less than B.

TABLE XI

Yield data

	A	B	C	D	E
Total dry matter (grams per pot)	19·0 19·0 18·6	27·4 28·2 26·0	16·6 15·4 15·2	22·4 22·6 22·3	14·0 13·7 10·8
Average	18·86	27·2	15·7	22·4	12·83
Grain yield (grams per pot)	6·8 5·5 4·8	7·0 6·5 6·8	4·7 3·2 4·4	5·8 5·9 5·3	3·3 3·8 3·3
Average	5·36	6·76	4·1	5·66	3·46
Number of grains (grains per pot)	239 220 189	289 243 264	213 191 217	227 225 207	127 140 129
Average	216	265·3	207·0	219·6	132

The results show that the application of castings increased yields. Mixing of the castings in the entire soil gave higher yields than mixing with the top 4 in. soil. Treatment B, (20 per cent of the castings mixed in the entire soil) gave the maximum yields, showing thereby that higher the percentage of castings higher the yield

Experiment 3

Comparison of the effect of equal doses of two types of castings on the productivity of soil

In this experiment small castings and large castings each 1 lb. in weight were spread on the top of the soil as to see that how the covering of the soil by the different types of castings as done in nature by earthworms, affected the yield of the crop.

Growth Studies. In the initial stages the growth rate was more in the case of small castings but later on the difference was made up by large castings and both exhibited almost equal growth. There was no difference in other growth factors, like number of tillers, number of leaves per plant and mean ear length.

Table XII

Yield data

Replication	Total dry matter (grams per pot)		Grain yield (grams per pot)		Number of grains	
	A	B	A	B	A	B
1.	14·17	11·40	4·60	3·4	161	120
2.	16·10	10·92	3·75	3·5	122	125
3.	9·87	9·27	2·70	2·7	100	110
Mean	13 38	10·53	3·68	3·2	127·6	118·3

Dry matter, grain yield and number of grains were all higher in the case of small castings than large ones. These results indicate that small castings give better results than the large castings, when even spread on the surface.

From the results presented above it is apparent that both the types of castings are more productive than the soil and the small castings are more productive than the large ones. Data presented in Table XI indicate that the application of small castings like manure in doses of 1 lb., 2 lb. and 4 lb. resulted in 18·2, 63·5 and 94·2 per cent increase in grain yields respectively.

The question arises why small castings prove more productive than the large ones, inspite of the fact that the latter contain 2 to 3 times more nutrients than the former, as will be evident from the data presented in Tables V and VI. So the higher yield of wheat produced by the small castings could not be attributed to their nutrient content. Therefore, the alternative was to study the physical properties of the castings, to see if it was not the difference in their physical make up, to which the differences in the yields could be attributed. Different physical characteristics of the castings given in Tables II to IV show that the structure of small castings is much better than the large castings and soil. Small castings have higher rate of percolation, low dispersion co-efficient and higher amount of water stable aggregates as compared to large castings and soil. This is being further supported by the observation that

there was greater decrease in volume of the large castings as compared to small castings when submerged under water for 24 hours ; the decrease in volume being 39·8 per cent and 6·45 per cent in the case of large and small castings respectively. All these observations support that the large castings will slake easily in water and the clay particles thus dispersed would clog the pores and decrease aeration and permeability.

In the light of above observations it becomes obvious that the physical make up rather than the nutrient status of the castings has been more potent in affecting the yield. The large castings which slake when submerged in water and contain less amount of water stable aggregates gave lower yields than the small castings inspite of the fact that these were rich in nutrients. Low amount of water stable aggregates in the large castings was responsible for higher dispersion and low rate of percolation, which is synonymous to defective aeration. The importance of aeration in affecting yields has already been established by Baver [1940] and Yoder [1937]. The former investigator found that when aeration was defective, in case of beets, no response could be got by the application of commercial fertilizers. The yields went up as the aeration of the soil was increased. Yoder also obtained the highest yield of seed cotton when non-capillary porosity was over 30 per cent. The presence of 1 to 3 mm. sized aggregates has been seen to affect the yield of crops by many investigators like Kvasnikov in Russia as quoted by Baver [1948] and Nijhawan *et al*. [1947] in India. The latter investigators found that in seed beds containing high amount of 1 to 3 mm. sized granules, higher yields were obtained.

These observations clearly point out to the fact that the increased yields in case of small castings when used alone mixed with the soil, can be attributed to their better physical make up. When these are either spread on the soil or mixed with it even in small doses they improve the aeration which increases yields. It has been observed that when irrigation is applied, crust is formed on the soil surface but such crust is absent in the case of small castings. This observation is in accordance with the findings of Baver [1948] who observed that unless water stable aggregates are present in the surface layer irrigation water causes dispersion of the secondary particles and thus decreases non-capillary porosity.

These results suggest that the addition of small castings to the soils poor in structure as the soils of the Punjab are, will increase the crop production. This preliminary work opens a new line of work that physical condition of the soil is as important if not more than its nutrient content in influencing the yield of crops and how earthworms can contribute in improving the physical condition of the soil.

Summary

In the Punjab two types of earthworm castings are met with, small and large. The small castings lie singly or in heaps on the surface of the soil or in the burrows of the earthworm. The large ones consist of huge tower like structures with a central channel. They lie on the surface only. Both the types are very common, though the large ones are much more common during the rainy season. The physico-chemical characteristics of both the types of castings, collected from different places

in the state and their effect on soil productivity have been studied and the main conclusions are as follows:

Both types of earthworm castings contain more coarse sand and less of finer soil separate (clay and silt) than the parent soil.

Dispersion co-efficient of the earthworm castings is lower than the parent soil and that of the small castings lower than the large ones.

Water percolates through the small castings much quicker than through the soil and the large castings. The large castings had the lowest rate of percolation.

Amount of water stable aggregates in both the types of castings was much higher than the parent soil. The large castings had a very high amount of water stable aggregates bigger than 3 mm. in diameter whereas the small ones had more of 1 to 3 mm. sized aggregates.

All samples of castings had higher amount of organic matter, total nitrogen and nitrates than the parent soil whereas C/N ratio was lower. The large castings were 2 to 3 times richer than the small castings in these nutrients.

Calcium carbonate and total calcium content of large castings was many times higher than the small ones and the parent soils. Phosphorous (total and available) potassium, manganese, exchangeable cations such as calcium, magnesium, potassium and sodium were more in large castings than the small ones, which has less of these nutrients even than the parent soils.

Earthworm castings were found to have lower *p*H value than the parent soils which were either neutral or alkaline. This shows the effect of earthworms in decreasing the *p*H of alkaline soils.

Chemical composition of the castings developed under different climatic conditions was found to vary with the climate similarly as that of the soil.

Earthworm castings are a very important contribution of earthworms to the soil and both the types of castings met in the Punjab State are more productive than the soil.

Small castings inspite of their lower nutrient content are more productive than the large castings. This is due to their better structure and the improvement in the physical condition of the soil brought by them when mixed with it or spread on its surface.

Application of small castings even in small doses as 1 lb. per 20 lb. of the soil increases the yield of the grains by 18 per cent but when their dose is 20 per cent i.e., 4 lb. per 20 lb. of soil, the yield is nearly doubled.

REFERENCES

Archangelski, M. (1929). The influence of earthworm activity on yield of oats and barley in relation to the application of various fertilizers. *J. Agric. Sci.* Russia ; **6**, 849

Bahl, K. N. (1947). *The Indian Zoological memoirs Pheretima*, 74-75

Bates, G. H. (1933). The distribution of white clover in relation to the activity of earthworms. *Welsch J. Agric.* **9**, 195-208

Baver, L. D. (1948). *Soil Physics* (published by Willey and Sons). 271

Baver, L. D. and Farnsworth, R. B. (1940). Soil structure effects in the growth of sugar beets. *Soil. Sci. Soc. Am. Proc.* **5**, 45-48

Chadwick, L. C. and Bradley (1948). An experimental study of effect of earthworms on crop production. *Proc. Am. Soc. Hort. Sci.* **51**, 552-562

Dawson, R. C. (1948). Earthworm Microbiology and the formation of Water Stable soil Aggregate. *Soil Sci. Soc. Am. Proc.* (1947) **12**, 512-526

Dutt, A. K. (1948). Earthworm and Soil Aggregation. *Amer. Soc. Agion. Jour.* **40**, 407-415

Evans, A. C. (1948). Studies on the relationship between earthworm and soil fertility. II. Some effects of earthworm on soil structure. *Am. Appl. Biol.* **35**, 1-13

Froud, M. D. (1948). Earthworms and soil fertility. *Agric. Prog.* 54-58

Hopp, H. and Hopkins, H. T. (1946). Earthworms as a factor in the formation of water stable soil aggregates. *J. Soil Water Cons.* **1**, 11-13

Hopp, H. and Slater, C. S. (1948). Influence of earthworms on soil productivity. *Soil Sci.* **66**, 421-428

Jenny, H. (1930). A study on the influence of climate upon the nitrogen and organic matter content of the soil. *Missouri Agr. Expt. Sta. Res. Bull.* 152

Jenny, H. (1941). *Factors of Soil formation*, Fourth Edition, 105-145

Lindquist, B. (1942). Investigations of the importance of some Scandanavian earthworms for the decomposition of broad leaf litter and for the structure of mull. *Rep. J. Agric. Res.* 1949, 325-339

Lunt, H. A. and Jacobson, H. G. N. (1944). The chemical composition of earthworm casts. *Soil Sci.* **49**, 367-375

Nijhawan, S. D. and Dhingra, L. R. (1947). Some characteristics of soil aggregates in cultivated soils of the Punjab. *Soil Sci. Soc. Amer. Proc.*

Nijhawan, S. D. and Olmstead, L. B. (1947). The effect of sample pretreatment upon soil aggregates in wet sieve analysis. *Soil Soc. Amer. Proc.*

Puh, Y. C. (1941). Beneficial influence of earthworms on some chemical properties of the soil. *Sci. Soc. China Biol. Lab. Contrib. Zool. Ser.* **15**, 147-155

Russel, E. J. (1909). The effect of earthworms on soil productiveness. *J. Agric. Sci.* (England) 3(11), 246-257

Russel, E. J. (1934). Rep. Soil condition and plant growth by Russel—8th Edition 1950, 413

Shrikhande and Pathak (1948). *Curr. Sci.* 327-328

Stephenson, J. and Beni Parshad (1919). The Calciferous glands of earthworms. *Trans. Roy. Soc. Edin.* **52**

Wollny, E. (1890). *Rep. J. Agric. Res.* 1949, 325-339

Yoder, R. E. (1937). The significance of soil structure in relation to the tilth problem. *Soil Sci. Soc. Amer. Proc. Prog.* **2**, 21-33

FIXATION OF NITROGEN IN RICE SOILS IN THE DRY PERIOD

By P. K. De and N. R. Datta Biswas, Department of Soil Science, Dacca University*

(Received for publication on 24 November, 1951)

(With Plate XXXI)

The conditions that exist in the rice-fields of India at different seasons of the year have been described elsewhere [De and Bose, 1938], and the name ' Dry period ' has been given to the few winter months after harvest when the soils remain dry and fallow. The average temperature during this period lies between 25° and 30° C. and there remains in the soils sufficient moisture to favour microbial growth. Moreover, a portion of straw is usually left in the field at harvest, which together with roots and stubble, might serve as an energy material for the nitrogen-fixing bacteria. The conditions of the soils during the dry period thus appear to be very favourable for nitrogen fixation, and it is possible that some fixation may take place at this stage. The present investigation has been undertaken to investigate this possibility.

A review of the literature shows that, except some isolated attempts, no detailed study of nitrogen fixation in rice-fields under dry conditions has ever been undertaken. De and Pain [1936] made some preliminary experiments with rice soils of Bengal and found that the amounts fixed in four soils were greater than the amounts removed annually by a rice crop. De and Bose [1938] studied the microbiological conditions existing in the rice soils at different seasons of the year and observed that the *Azotobacter* numbers remained more or less at a stationary level at different periods except in the early stage of water-logging when a decrease takes place. Sahasrabuddhe and Abhyankar [1936] reported that the cropped rice plot shows more nitrogen than the uncropped rice plot during the growing period of the rice crop. In a later communication Sahasrabuddhe [1936] observed much greater fixation of nitrogen by *Azotobacter* in Ashby's solution when a rice plant was present, from which it was concluded that the growing roots of the rice plant help nitrogen fixation. Uppal, Patel and Daji [1939] made similar observation on the basis of which they concluded that *Azotobacter* plays an important role in the nitrogen recuperation of rice soils at Karjat (Bombay). Recently Willis and Green [1948] found that gains in nitrogen as a result of fixation under the conditions prevailing in rice fields during the growing season may be equivalent to or greater than the amount of nitrogen utilised by the crop.

Demonstration of an actual increase in nitrogen in soils is admittedly the most crucial test of nitrogen fixation. Such a demonstration, however, is often a very difficult task, because the magnitude of the errors of the experiment is generally so great as to make it almost impossible to detect with accuracy small differences in

* The work described in this paper was done before the senior author (P. K. De) left the Dacca University in September, 1947

nitrogen contents of soils. In a recent communication Lander and Madhok [1940] have shown that a difference of gain or loss of 28 lb. of N per acre cannot be detected with certainty by Kjeldahl method of nitrogen estimation if the sample taken for analysis is 10 gm. In experiments made in this laboratory it has been found that nitrogen fixation to the extent of 37 lb. per acre can not be demonstrated by determination of nitrogen of soil before and after the experiment. Unless, therefore, the fixation is large, direct proof of nitrogen fixation is difficult to obtain.

Some indirect evidences as to the possibilities of fixation taking place in a soil may, however, be obtained by a study of the microbiological conditions that exist there. According to present state of our knowledge, only three groups of microorganisms are definitely capable of fixing element nitrogen without symbiosis with a host plant.

(1) Aerobic bacteria of the genus *Azotobacter*.

(2) Anaerobic bacteria of the genus *Clostridium*, represented by the species *Clostridium pasteurianum*.

(3) Certain blue-green algae.

Of these algae are active in water-logged soils, while *Clostridium pasteurianum* an anaerobic organism found nearly all soils, can fix nitrogen only in water-saturated soils supplied with sugar or starch. Moreover, their yield of fixed nitrogen per unit of consumed energy material is lower than in *Azotobacter*; their activity, therefore, can hardly be credited with any practical significance under the conditions obtaining in the rice soils during dry period. From all these considerations it is assumed that if there be any fixation of nitrogen in the rice soil during the dry period, it will be brought about by *Azotobacter*, since the soil conditions are suitable only for their growth. Thus, if the conditions of the rice soils during the dry period are found to be favourable for *Azotobacter* growth, it will at least indicate a possibility of some nitrogen fixation taking place at this stage.

The object of the present investigation is, firstly, to find out whether any measurable amount of nitrogen is fixed in the rice soils when kept under conditions similar to those occurring in the field during the dry period, and secondly, to ascertain how far the above conditions are suitable for the growth of *Azotobacter*.

Experimental

Experiment on the fixation of nitrogen in rice soil

In order to find out whether measurable amounts of nitrogen are fixed in the rice soils under dry conditions, 50 gm. portions of air-dried and sieved (2 mm.) soils were distributed in 250 c.c. Erlenmeyer flasks, which were divided into 2 sets—one set remaining untreated and to each flask of the other set 0·1 gm. of powdered rice straw, was added and thoroughly mixed. After the moisture content of the soils had been adjusted to 15 per cent on dry basis, the flasks were plugged with cotton wool, weighed and then exposed to sunlight in the pot culture house. The experiment was done in the winter so that the temperature and the light conditions were very nearly similar to those occurring in the rice-fields during the dry period. Each

flask was vigorously shaken daily so that the conditions of the soil might remain strictly aerobic throughout the experiment. Every third day the flasks were removed to the laboratory, weighed and the loss in weight made good by the addition of requisite amount of water. No algal growth, so frequent and abundant in the rice soils under water-logged conditions, was noticed, except that a very thin green coating, presumably consisting of green algae, appeared on the inside bottom of a few flasks. At intervals of 25 days, duplicate flasks from each treatment were removed, the contents of each taken out and powdered after which two 15 gm. portions were analysed for total nitrogen by the Kjeldahl method.

The results in Table I show that only in one soil, namely, Gaya treated with straw, has there been fixation of nitrogen to any measurable extent. In other soils, the fixation, although mostly positive, is not large enough to lead to any definite conclusion. It is possible that in these soils small amounts of nitrogen not estimable by direct analysis, might have been fixed, but unless supported by other facts, such a conclusion will be hardly justifiable.

TABLE I

Changes in nitrogen contents of different rice soils

(N in mgm. in 100 gm. of even dry soil)

Soils and treatments	Nitrogen					N gain calculated as lb. per acre
	At start	After 25 days	After 50 days	After 75 days	Gain in 75 days	
Karimganj (Assam)						
Control	93·8	92·8	93·1	93·9	0·1	2·0
Straw	94·5	93·2	94·6	95·0	0·5	10·0
Titabari (Assam)						
Control	112·9	111·9	111·5	113·2	0·3	6·0
Straw	113·5	112·1	114·0	114·4	0·9	18·0
Kankee (Bihar)						
Control	49·3	48·1	..	49·0	—0·3	—6·0
Straw	50·0	49·0	..	50·2	0·2	4·0
Sabour (Bihar)						
Control	113·0	114·3	114·4	114·0	1·0	20·0
Straw	113·6	115·0	114·0	114·8	1·2	24·0

TABLE I *contd.*

Changes in nitrogen contents of different rice soils

(N in mgm. in 100 gm. of even dry soil)

Soils and treatments	Nitrogen					N gain calculated as lb. per acre
	At start	After 25 days	After 50 days	After 75 days	Gain in 75 days	
Gaya (Bihar)						
Control	55·7	..	..	56·7	1·0	20
Straw	56·3	..	..	58·7	2·4	48
Coimbatore (Madras)						
A Block						
Control	71·4	71·3	71·4	70·0	—1·4	—28
Straw	72·1	73·2	73·1	74·0	1·9	38
B Block						
Control	70·3	..	71·9	71·4	1·1	22·0
Straw	71·0	..	74·0	72·9	1·9	38·0
Faridpur I (Bengal)						
Control	49·3	49·3	49·1	50·6	1·3	26·0
Straw	50·0	49·9	49·8	51·2	1·2	24·0
Faridpur II (Bengal)						
Control	149·1	149·1	149·8	149·7	0·6	12·0
Straw	149·8	149·6	149·7	150·0	0·2	4·0

Changes in Azotobacter numbers

Nitrogen fixation being a function of the growth of the nitrogen-fixing organisms, it would be expected that there will be a considerable increase in the numbers of the latter in a soil in which fixation takes place. Thus if there is any fixation in rice soils during the dry period, this will be accompanied by a large increase in the number of *Azotobacter*. The following experiment was accordingly undertaken to determine the changes in *Azotobacter* number in rice soils under dry period conditions.

Two hundred gram portions of soils were distributed into two glass dishes of which one received a treatment of 0·5 gm. of coarsely powdered rice straw. After the moisture content of the soils had been adjusted to 12 per cent on the dry basis, —a value to which it was maintained throughout the experiment, the dishes were loosely covered and kept in an incubator at 32°C., the soil being stirred daily to facilitate aeration. For counting, samples were withdrawn by means of a sterile cork-borer, and were thinly spread over filter paper and then dried in the incubator for 2 hours. The dried soil was powdered, a portion being used for inoculation of the plates and another for moisture determination.

The method used for *Azotobacter* counts was essentially the same as that described by Winogradsky [1925] with the modification that agar was substituted for silica gel in the preparation of the medium*. Preliminary trials have shown that parallel counts by this method are more concordant than by sillica gel plate method; although the latter medium is more selective for *Azotobacter* growth. Portions of finely powdered soils, equivalent to 0·1 gm. on dry basis, were evenly spread by means of a fine gooch crucible over the surface of each of three hardened agar plates (18 cm. diam.), the colonies formed after 68 hours incubation at 32°C. were counted.

A reference to Table II will show that the *Azotobacter* numbers, after a sharp fall within the first 15 days, remained almost at a stationary level for the rest of the period. It is further noted that straw had a depressing effect on *Azotobacter* growth ; in every instance its number in the presence of straw was much less than in the corresponding controls. The effect of straw on *Azotobacter* will be discussed in a later part of this paper along with the results of bacterial and fungal counts. The present results thus show that the conditions in rice fields during the dry period are not favourable for *Azotobacter* growth.

TABLE II

Changes in Azotobacter colonies in rice soils

Days	Soils					
	Faridpur		Sabour		Coimbatore B. Block	
	Control	Straw	Control	Straw	Control	Straw
0	110	110	358	358	532	532
	115	115	365	365	542	542
	109	109	363	363	544	544
	(111)	(111)	(362)	(362)	(539)	(539)

*K_2HPO_4—0·5 gm., $MgSO_4$, $7H_2O$—0·2 gm., NaCl—0·2 gm., $CaCl_2$, $2H_2O$—0·05 gm. $FeCl_3$—Trace, $CaCO_3$ –10 gm., Mannite –5 gm., Agar –15 gm., Water –1000 c.c.

TABLE II *contd.*

Changes in Azotobacter colonies in rice soils

Days	Soils					
	Faridpur		Sabour		Coimbatore B. Block	
	Control	Straw	Control	Straw	Control	Straw
15	83	62	327	245	388	300
	82	60	333	241	406	292
	84	60	324	241	416	286
	(83)	(61)	(328)	(242)	(403)	(292)
30	71	53	326	280	414	270
	72	56	312	292	436	266
	74	51	313	286	442	274
	(72)	(53)	(317)	(286)	(430)	(270)
45	76	57	299	274	346	278
	74	50	301	274	348	292
	78	47	305	266	338	286
	(76)	(51)	(301)	(271)	(344)	(285)
60	65	48	301	269	364	298
	66	49	303	273	356	300
	67	48	298	275	370	..
	(66)	(48)	(300)	(272)	363)	(299)

(Figures represent the number of colonies in each plate ; averages in parentheses)

Further examination of the suitability of the soils for Azotobacter growth

Among the more important factors influencing the growth of *Azotobacter* in soils are (*a*) energy materials (*b*) available phosphate and (*c*) available nitrogen compounds. While a liberal supply of the first two is essential for a vigorous multiplication of *Azotobacter*, the presence of the last in sufficient amount has, on the other hand, a depressing effect upon its development in soils. The following experiments were undertaken to find out to what extent the conditions of rice soils in the dry period, with regard to the above factors, are suitable for *Azotobacter* growth.

(*a*) *Energy material*

As stated before, a portion of rice straw is usually left in the field at harvest. This together with the rice roots might serve as energy materials for nitrogen fixation. To investigate this, 100 c.c. portions of a nitrogen-free mineral so'ut'ons (P. 379) containing 1 gm. of finely chopped straw or root were inoculated with 1 gm. of soil and then ncubated at room temperature for two months. The cultures were daily shaken during the experiment to facilitate aeration. Straw appeared to undergo rapid decomposition ; there was copious evoluton of H_2S and the so ut'on turned brown, gradually becoming deeper in colour, while the straw itself was converted almost to a pulp. Roots, on the other hand, showed no noticeable change, there being no gas evolution and the colour of the solution remaining almost the same as at start. At the end of 30 and 60 days the cultures were analysed for total nitrogen. The results are given in Table III.

TABLE III

Nitrogen fixed in culture solution when rice straw and roots are used as sources of energy

Energy material	Soils used for inoculation	N in mgm. in 100 c.c. of the medium					*Azotobacter*
		At start	After 30 days	Fixed in 30 days	After 60 days	Fixed in 60 days	
Straw	Faridpur	4·9	9·2	4·3	..	..	C
	Kankee	4·9	8·8	3·9	..	..	C
	Coimbatore B Block	5·0	10·6	5·6	11·2	6·2	C
	Karimganj	5·3	7·3	2·0	9·2	3·9	I
Straw	Sibsagar	5·7	7·3	1·6	9·4	3·7	I
	Sibsagar ($CaCO_3$ omitted).	5·7	7·7	2·0	8·2	2·5	I
	Sabour	5·4	9·0	3·6	9·7	4·3	C
	Gaya	4·8	7·1	2·3	9·4	4·6	C
	Titabari ($CaCO_3$ omitted).	5·5	8·2	2·7	9·9	4·4	I
	Titabari	5·5	9·7	4·2	9·8	4·3	I
Root	Sibsagar ($CaCO_3$ omitted).	8·2	8·3	0·1	8·3	0·1	
	Faridpur	7·5	8·3	0·8	8·4	0·9	
	Coimbatore B Block.	7·6	..	..	9·1	1·5	
	Titabari	8·1	..	..	8·5	0·4	

C denotes occurrence of *Azotobacter chroococcum*
I " " " " *indicum*

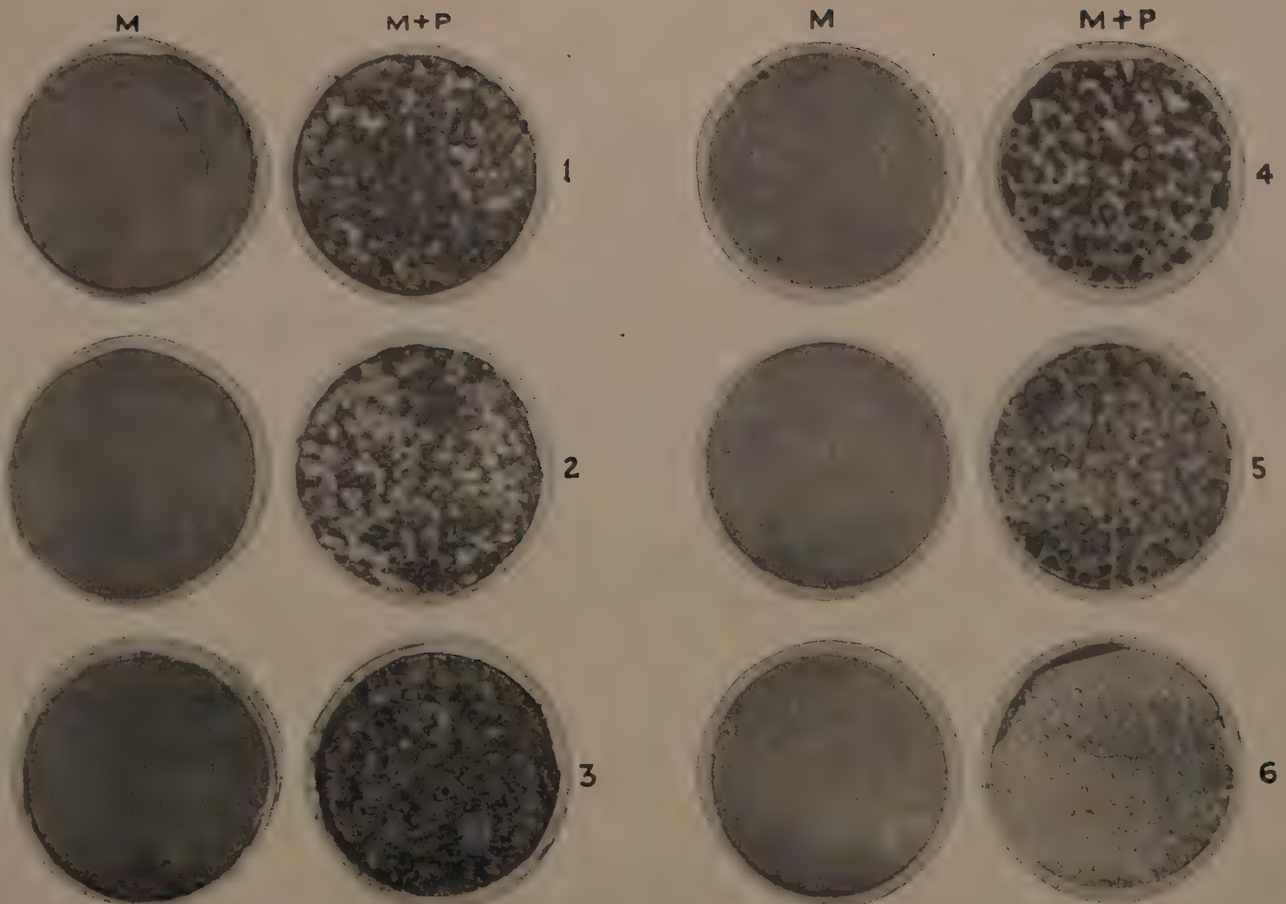
Since the moisture content of the soil at dry period is much less than that in a culture solution, the above experiment was repeated w:th a limited supply of

TABLE V

Influence of phosphate on the development of Azotobacter on soil plaques

Soil		pH	Number of *Azotobacter* colonies in 1 sq. cm. No phosphate	Number of *Azotobacter* colonies in 1 sq. cm. Phosphate
Experiment 1	Coimbatore A. Block	8·4	1	41
	Coimbatore B. Block	8·4	0	44
	Coimbatore N. Block	8·5	0	57
	Gaya	8·0	0	28
	Sabour	8·3	0	72
	Faridpur I	8·5	0	*
	Faridpur II	7·1	0	*
	Kankee	7·8	0	*
Experiment 2	Faridpur I	..	0	*
	Faridpur II	..	0	*
	Kankee	..	0	*
Experiment 3	Sibsagar	5·9	0	0
	Karimganj	5·0	0	0
	Titabari	5·0	0	0
	Tipperah I	6·3	0	0
	Tipperah II	6·0	0	0
	Tipperah III	6·2	0	0
Experiment 4	Faridpur I		0	0
	Faridpur II		0	Abundant growth
	Kankee		0	,,
	Sibsagar		0	,,
	Titabari		0	,,
	Tipperah (3 soils)		0	,,

* No *Azotobacter* growth took place, but some small white colonies not becoming black on standing, were noticed.



Soil plaques made from different rice soils Approximately natural size

M. denotes treatment with mannital

M + P denotes treatment with mannital and K_2HPO_4.

1. Sabour soil. 2. Faridpur soil II (sterilised and inoculated with *Azotobacter chroococcum*).

3. Sibsagar soil (sterilised, treated with $CaCo_3$ and inoculated with *Azotobacter chroococcum*).

4. Coimbatore soil. B. Block. 5. Coimbatore soil. N. Block. 6. Kankee soil.

Experiment 2. Some of the soils in the above experiment did not show *Azotobacter* growth even after the addition of phosphate. In this experiment, those soils were first treated with 20 per cent Kaolin and then the test applied (Table V).

Experiment 3. Soils not containing *Azotobacter chroococcum* were used in this experiment. They were first treated with 3 per cent $CaC0_3$ and then inoculated with a suspension of the above organism. These soils were then tested (Table V).

Experiment 4. Soils not showing growth even after treatment with phosphate in experiments 1 to 3 were sterilised, inoculated with *Azotobacter* and then examined in the usual way (Table V).

The results of Experiment 1 show that the first five soils are highly deficient in phosphate, since an abundant growth of *Azotobacter* took place only when this mineral was supplied. The last three soils, namely, Faridpur I, Faridpur II and Kankee did not show growth even on addition of phosphate. This observation, while not ruling out the possibility of phosphate deficiency, suggests that some other factor has prevented *Azotobacter* growth in these soils. The same is true of the acid soils (Experiment 3) in which there was not growth even after addition of lime and phosphate, and on inoculation with *Azotobacter*. The results of Experiment 4 are very interesting. Here all the soils, with the exception of Faridpur I soil, showed abundant growth only in presence of phosphate, showing thereby that these soils are really deficient in this mineral. The fact that growth took place in these soils when sterilised, while under exactly identical conditions no growth took place in unsterilised soils, suggests that absence of growth in the latter case is probably due to competition with other organisms ; when these organisms were killed by sterilising the soils, *Azotobacter* found conditions favourable for growth. The absence of growth in Faridpur soil I, however, might be due to a different cause.

Thus, altogether 14 rice soils, obtained from different localities, were examined and all of them have been found to be highly deficient in phosphate at least for vigorous development of *Azotobacter*. The results have further shown that, besides energy and phosphate, other undeterminable factors may also prevent *Azotobacter* growth in soil.

Plate XXXI gives the photographs of some of the soil plaques, from which the phosphate deficiency in soils becomes clearly evident.

(*c*) *Available nitrogen compounds*

Another important factor that might influence the fixation of nitrogen by *Azotobacter* is the presence of available nitrogen compounds in soils. These compounds may affect the growth of *Azotobacter* in two ways. In the first place, they may encourage the growth of other organisms, particularly when an energy material is present, and in the process of their growth, these organisms may compete with *Azotobacter* for available nutrients. Secondly, when available nitrogen is present *Azotobacter* itself may assimilate it for growth, without having the necessity of fixing atmospheric nitrogen.

In order to have some knowledge of the extent of accumulation of available nitrogen compounds in rice soils during dry period, an experiment was performed in which 50 gm. portions of soils, with and without addition of straw and maintained at a moisture content of 12-13 per cent were kept at room temperatures with frequent stirring to facilitate aeration. At intervals, duplicate samples from each treatment were removed and the ammonia and nitrate determined by Olsen's method [1929]. The results are given in Table VI.

TABLE VI

Ammonia and nitrate contents of soils

(*N as p. p. m.*)

Days	Faridpur soil				Coimbatore Soil A. Block			
	NH_4—N		NO_3—N		NH_4—N		NO_3—N	
	Control	Straw	Control	Straw	Control	Straw	Control	Straw
0	4·2	4·2	4·5	4·5	14·0	14·0	5·0	5·0
15	1·1	3·5	21·8	1·7	1·1	0·0	13·7	0·8
30	0·6	1·4	20·7	1·7	0·8	1·4	15·7	0·6
45	0·6	1·1	19·6	2·2	0·6	1·1	23·8	1·4
60	0·8	1·1	25·5	2·8	0·8	1·1	18·5	1·1

The most striking feature of the results is the accumulation of large amounts of nitrate in the control soils as compared with little in the presence of straw. This observation would tend to suggest that straw makes the conditions favourable for *Azotobacter* growth by preventing nitrate accumulation. Such a conclusion, however, does not receive support from the results of *Azotobacter* counts which showed considerable reduction in the number of the organism when straw was added to the soils (Table II). The loss of nitrate in the presence of straw was probably due to the assimilation of the nitrogen compounds made available in the process by the micro-organisms resulting in an abundant multiplication of the latter. To test this view, soil cultures were set up as above and the numbers of bacteria including actinomyces and fungi were determined at intervals. The former was estimated by plating 1 c.c. portions of a soil dilution of 1 : 250,000 on Thornton's agar [1922] and incubating the plates at 30°C for 7 days and the latter by plating on Waksman's peptone glucose agar [1922], using a dilution of 1 : 25,000 for samples treated with straw and 1 : 2,500 for controls, the incubation period being 3 days at 30°C. For every count five parallel plates were run. The results are given in Table VII.

TABLE VII

Changes in bacterial and fungal numbers. Bacteria including actinomyces as millons and fungi as ten thousands per gram of oven dry soil

Days	Faridpur soil				Coimbatore soil, A. Block			
	Bacteria		Fungi		Bacteria		Fungi	
	Control	Straw	Control	Straw	Control	Straw	Control	Straw
0	1·3	1·3	0·8	0·8	3·3	3·3	4·9	4·9
10	12·3	18·0	6·6	29·6	8·3	27·9	6·9	37·8
20	15·7	31·9	3·2	63·3	14·8	32·1	6·3	70·4
30	23·4	35·4	4·8	58·3	14·9	65·2	7·0	73·3

The results in Table VII show that there was an abundant growth of micro-organisms in the soils specially when treated with straw. From this observation it would appear that the depressing effect of straw on nitrate accumulation and on *Azotobacter* growth is due to the multiplicaton of heterotrophic organisms of the soils which, while assimilating the available nitrogen compounds for their development, compete with *Azotobacter* for supply of other nutrients thereby suppressing the growth of the latter. The present experiment thus affords another evidence that the conditions occurring in rice-fields during the dry period are not suitable for *Azotobacter* growth.

CONCLUSION

The problem has been attacked from different angles and the evidences obtained all point to the same conclusion, namely, no fixation of nitrogen takes place in rice fields during dry period.

SUMMARY

The object of the investigation is (1) to find out whether any measurable amount of nitrogen is fixed in the rice soils during the dry period, and (2) to ascertain how far the conditions existing in the soils during the said period are suitable for *Azotobacter* growth.

Several rice soils from different parts of India were maintained at a moisture content of 15 per cent with and without the addition of straw. Determination of total nitrogen after 75 days showed significant increase only in one instance. *Azotobacter* count in some of the above soils showed a sharp decrease within the first 15 days after which the level remained more or less stationary. In the presence of straw, the numbers were considerably less than in its absence.

Inoculation of a nitrogen-free culture solution containing either rice root or straw as an energy materials with soils gave in 60 days an average fixation of 5 mg. of nitrogen per gram of straw but nothing with root. When, however, the moisture

supply was reduced in the above experiment so as to keep the straw just wet, no fixation of nitrogen took place.

Fourteen rice soils were examined by soil plaque method and were found highly deficient in phosphate.

The addition of straw to the rice soil considerably stimulated bacterial and fungal growth but depressed nitrate formation. In the absence of straw on the other hand, nitrate accumulation was considerable and microbial growth much less abundant. These observations suggest that the depression of *Azotobacter* growth in the presence of straw is due to the competition with the heterotrophic micro-organism of the soil for supply of available nutrients.

The evidences obtained above indicate that no nitrogen fixation to any measurable extent takes place in rice soils during the dry period and that the conditions occurring in the soil during the said period are not suitable for *Azotobacter* growth.

REFERENCES

De, P. K. and Bose, N. M. (1938). A study of the microbiological conditions existing in rice soils. *Indian J. agric. Sci.* **8**, 487-498

De, P. K. and Pain, A. K. (1936). A Biochemical study of the paddy Soils of Bengal with special reference to their nitrogen-fixing capacities. *Indian J. agric. Sci.* **6**, 746-756

Jensen, H. L. (1939). Contribution to the nitrogen economy of Australian wheat soils, with particular reference to New South Wales. *Proc. Linn. Soc., New South Wales*, **65**, 1-122

Lander, P. E. and Madhok, M. R. (1940). On the index of nitrogen level in soils. *Indian J. agric. Sci.*, **10**, 773-775

Olsen, C. (1929). On the analytical determination of ammonia in soils, and the adsorption power of soil for ammonia. *Compt. Rend. Lab. Carlsberg* **17**, No. 15

———(1932). Nitrogen fixation in the dead leaves from forest beds. *Compt. Rend. Lab. Carlsberg* **19** : No. 9

Richards, E. H. (1917). The fixation of nitrogen in faices. *J. agric. Sci.* **8**, 299-311

Sahasrabuddhe, D. L. (1936). Fixation of nitrogen by rice soil and rice plants. *Proc. Ind. Acad. Sci. Soc. B*, **3**, 310-319

——— and Abhyankar ; V. S. (1936). Nitrogen recuperation in the soils of Bombay Presidency, Part IV. *Indian J. agric. Sci.*, **6**, 268-315

Thornton, H. G. (1922). On the development of standardised agar medium for counting soil bacteria with special reference of spreading colonies. *Ann. Appl. Biol.* **9**, 241-247

Uppal, B. N., Patel, M. K., and Daji, J. A. (1939). Nitrogen fixation in rice soils. *Indian J. agric. Sci.* **9**, 689-702

Waksman, S. A. (1922). A method for counting number of fungi in soil. *J. Bact.* **7**, 339-341

———(1932). *Principles of Soil Microbiology*

Willis, W. H. and Green, V. E. (1948). Movement of nitrogen in flooded soil planted to rice. *Soil Sci. Soc. America*, **13**, 229-237

Winogradsky, S. (1925). Soil Microbiology I. Nitrogen fixing bacteria. *Ann. Inst. Pasteur* **39**, 299-354

——— (1926). Soil Microbiology II. Nitrogen fixing bacteria. *Ann. Inst. Pasteur*, **40**, 455-520

MANURIAL VALUE OF AMMONIUM NITRATE ALONE AND ADMIXED WITH VARYING PROPORTIONS OF T. N. T.

By S. Sen, Sher Singh Bains, Indian Agricultural Research Institute, New Delhi and Y. C. Gupta, Agricultural Sub-Station of Indian Agricultural Research Institute, Karnal

(Received for publication on 26 September, 1950)

AMMONIUM nitrate, though used as an explosive, has also been recognised as a valuable concentrated nitrogenous fertilizer because of its solubility and composition. It is readily available to plants as soon as it dissolves in the soil solution. In addition, as it contains nitrogen in both the nitrate and ammoniacal forms, it is ideally suited for grass crops and other crops that prefer nitrogen in both forms.

Ammonium nitrate can be applied before the crop is planted or as side and top dressing. Fitts [1945] of the Nebrasca Experiment Station secured better distribution of ammonium nitrate by applying it in irrigation water and almost as good crop response as that obtained from side dressing. Skinner [1944] reporting the results of 23 cotton tests conducted in North and South Carolina concluded that on sandy loam soils ammonium nitrate was as good a fertilizer as ammonium sulphate or sodium nitrate. Skinner and Buie [1926] comparing ammonium sulphate and ammonium nitrate as the fertilizing materials for cotton and corn observed that on the sandy loam soils of South Carolina, both the fertilizers produced equally good yields. Paden [1939] from his concrete frame experiments observed that on soils with *p*H varying from 6·0 to 6·5 ammonium sulphate and ammonium nitrate produced practically the same results with cotton. Borden [1935] studying the effect of ammonium sulphate and ammonium nitrate on the yield of Sudan grass concluded that on soils with a *p*H 5·6, ammonium nitrate was superior to ammonium sulphate; on soils with *p*H 6·5, both the fertilizers produced the same results; on soils with *p*H 7·1, ammonium sulphate was superior to ammonium nitrate and on soils with a *p*H of 7·5, ammonium sulphate and ammonium nitrate gave practically the same results. Skinner, Williams and Mann [1929] concluded that ammonium nitrate can be usefully employed as a fertilizer for cotton and sweet potatoes.

T. N. T. (tri-nitro-toluene), a highly explosive chemical, has been used extensively in combination with ammonium nitrate during the last two World Wars. On the cessation of hostilities after the second World War, huge stocks of ammonium nitrate admixed with varying proportions of T. N. T. were found surplus. The use of this stuff as a fertilizer was thought to be the best way of its utilization in the peace time. Field experiments to assess the manurial value of ammonium nitrate were started at various places in India after the War, and the results of

12

those conducted at the Indian Agricultural Research Institute, New Delhi and at its Sub-Station, Karnal are reported here. The chemicals were supplied free of cost for these experiments by the War Department of the Government of India.

Experimental

The test crops used were sorghum, wheat, cotton, maize at New Delhi and paddy at Karnal. Ammonium sulphate, the most commonly used nitrogenous fertilizer, was also included in these trials for its comparison with ammonium nitrate.

The following uniform fertilizer treatments were given to different crops each year for the durations of these trials, except in the case of maize to which fertilizers were applied at 20 lb. N per acre.

Fertilizer treatment	*Amount of nitrogen applied per acre in lb.*
A. No manure (Control)	
B. Ammonium sulphate	40·0
C. Ammonium nitrate	40·0
D. Ammonium nitrate+T.N.T. 1 per cent	40·0
E. Ammonium nitrate+T.N.T. 2 per cent	40·0
F. Ammonium nitrate+T.N.T. 3 per cent	40·0

In Table I are given the details of lay-out and other information relating to these experiments. The fertilizers were applied before sowing the crops, except in the case of cotton, which was top dressed at the thinning and flowering times.

Table I

Lay-out and other details regarding experiments

Crop	Design of lay-out	Number of replications	Plot size (Acre)	Duration of trial	Location
Sorghum	Randomised Blocks	4 in 1944 6 in 1945-46	1/40	1944, 1945 & 1946 (3 years)	Main Bl. 3-C, 3-A & Sh. A
Wheat	Do.	4	1/20	1944-45 & 1945-46 (2 years)	Main Bl. 9-A
Maize	Do.	4	1/20	1945 (1 year)	Main Bl. 9-A
Cotton	Split-plot	2	1/40	1944 & 1945 (2 years)	Main Bl. 3-C
Paddy	Randomised Blocks	6	1/40	1944, 1945, 1946 (3 years)	Block VII

The soil under the experiments was light loam with a pH of 7·3 at New Delhi and a typical paddy (clayey) soil with pH value of 8·1 at Karnal.

Season

The rainfall figures of New Delhi and Karnal for the period these experiments were in progress are given in Table II.

TABLE II

Rainfall in inches

Month	New Delhi			Karnal		
	1944-45	1945-46	1946-47	1944-45	1945-46	1946-47
June	4·2	0·7	4·4	1·90	1·29	7·44
July	11·4	7·3	6·4	9·22	4·31	4·05
August	1·2	6·0	4·0	3·06	9·21	5·35
September	7·7	10·6	2·1	4·06	15·32	0·47
October	2·6	0·3	0·1	0·25	0·03	0·72
November	..	..	..	..	..	..
December	..	..	0·4	0·08	..	0·32
January	1·1	..	0·4	2·08	..	1·35
February	..	0·9	0·6	..	0·90	1·14
March	..	..	1·0	0·07	0·52	0·42
April	0·2	..	..	0·56	0·04	..
May	0·3	0·7	0·6	0·30	0·60	0·33
TOTAL	28·7	26·5	20·0	21·58	32·22	21·59

Yield results

Sorghum. Yields of sorghum green fodder obtained are given in Table III.

TABLE III

Yield of sorghum (Purbi) *green fodder in maunds per acre*

Fertilizer treatment	1944	1945	1946
A. No manure (Control)	389·00	284·49	390·54
B. Ammonium sulphate	463·75*	322·31*	421·63*
C. Ammonium nitrate	476·75*	329·20*	402·80
D. Ammonium nitrate+T.N.T. 1 per cent	427·25	320·13*	408·77
E. Ammonium nitrate+T.N.T. 2 per cent	463·75*	309·52*	417·88*
F. Ammonium nitrate+T.N.T. 3 per cent	475·25*	315·35*	395·30
C. D. at the 5 per cent level of significance	69·52	25·06	23·68

'F' test significant at 5 per cent level.

*Yields significantly higher than the control.

From the yield figures of sorghum green fodder given above, it will be seen that the application of ammonium nitrate alone or admixed with T. N. T. gave significantly higher yields than the 'no manure' control. During 1946, however, this effect due to ammonium nitrate was somewhat less marked than ammonium sulphate, but the differences were not significant. Ammonium sulphate all along produced significantly high yields over the control.

Wheat and maize. The wheat crop of 1944-45 was followed by maize to which the fertilizers were applied at the rate of 20 lb. N per acre. Maize was again followed by wheat in 1945-46. The results obtained are given in Table IV.

TABLE IV

Yield of wheat and maize in maunds per acre

Fertilizer treatment	Wheat C. 518 1944-45	Maize P.F. 2 *Kharif* 1945	Wheat C. 518 1945-46
A. No manure (Control)	43·39	11·99	12·39
B. Ammonium sulphate	38·93	13·19	26·42*
C. Ammonium nitrate	40·85	14·93*	23·52*
D. Ammonium nitrate+T.N.T. 1 per cent	39·86	13·06	26·42*
E. Ammonium nitrate+T.N.T. 2 per cent	39·14	15·10*	26·05*
F. Ammonium nitrate+T.N.T. 3 per cent	39·86	14·97*	23·71*
C. D. at the 5 per cent level of significance	4·24	2·93	5·51

'F' test significant at 5 per cent for *kharif* 1945 and *rabi* 1945-46.

*Yields significantly higher than the control.

The wheat crop during the year 1944-45 was sown in a field which was lying fallow during the previous *kharif* season. The crop of the manured plots was so bumper that it lodged badly in March and was affected by rust, whereas the crop in the no manure plots stood up well with the result that the yields of the manured plots remained lower than the control. The yields of the second crop of wheat (1945-46) were lower than that of the year 1944-45, because an exhaustive crop of maize preceded the wheat crop of 1945-46, and the response to the added nitrogen was well marked. In the case of maize (*Kharif* 1945), ammonium nitrate alone or with T. N. T. (2 and 3 per cent) gave significantly higher yields than the control. The differences between the fertilizer treatments, however, were not significant. Similarly, the effect due to different treatments was highly significant over the control for wheat in 1945-46.

Cotton. As indicated before, the fertilizers were applied (i) at the thinning time in July and (ii) at the flowering time at the end of August. The yields of seed cotton are given in Table V.

TABLE V

Yield of seed cotton (L. S. S.) in maunds per acre

Fertilizer treatment	1944 Applied at		Average for sub-plot treatment	1945 Applied at		Average for sub-plot treatment
	Thinning time	Flowering time		Thinning time	Flowering time	
A. No manure (Control)	9·84	8·37	9·11	9·83	8·17	9·00
B. Ammonium sulphate	10·81	10·59	10·70*	10·87	12·11	11·50*
C. Ammonium nitrate	10·15	10·50	10·33*	12·11	12·22	12·20*
D. Ammonium nitrate + T.N.T. 1 per cent	9·62	9·37	9·50	12·27	12·05	12·20*
E. Ammonium nitrate + T.N.T. 2 per cent	10·56	9·75	10·16	11·76	10·45	11·11*
F. Ammonium nitrate + T.N.T. 3 per cent	10·50	8·25	9·37	14·20	13·42	13·80*
Average for main plot treatment	10·25	9·47	..	11·84	11·41	..

'F' test significant at 5 per cent for fertilizer treatments.

*Yields significantly higher than the control.

	1944	1945
C. D. at the level of 5 per cent for main-plot treatment.	1·21	3·57
C. D. at the level of 5 per cent for sub-plot treatment	1·15	1·30
C. D. for interactions	2.81	3·68

In 1944, though all the treated plots gave higher yields than the control, ammonium sulphate and ammonium nitrate alone showed significant increases over the control, whereas in 1945 all the fertilizer treatments gave significantly high yields over the control. Although the differences in yield due to the application of fertilizers at different times were not significant, the earlier application showed slightly better results than that at the flowering time. There was a slight depressing effects due to T. N. T. but it was not significant.

Paddy N. P. 130. The yields of paddy due to different fertilizer treatments are given below. The fertilizers were applied a few days after transplanting.

TABLE VI

Yield of paddy N. P. 130 in maunds per acre

Fertilizer treatment	1944	1945	1946
A. No manure (Control)	24·24	32·14	33·46
B. Ammonium sulphate	28·70	34·24	40·11*
C. Ammonium nitrate	22·49	31·72	39·58*
D. Ammonium nitrate+T.N.T. 1 per cent	25·29	34·24	37·73
E. Ammonium nitrate+T.N.T. 2 per cent	22·05	33·19	38·31*
F. Ammonium nitrate+T.N.T. 3 per cent	25·38	33·51	36·26
C. D. at the 5 per cent level of significance	7·65	3·38	4·84

'F' test significant at 5 per cent level for 1946.
*Yields significantly higher than the control.

In 1944 and 1945, yields due to different fertilizer treatments did not show significant differences over the control, as paddy was rotated with berseem which masked the response due to different fertilizers. In 1946, paddy was sown after paddy with a fallow in between, and the response of the fertilizers was well marked. Ammonium sulphate, ammonium nitrate alone and with T. N. T. (2 per cent) gave significantly higher yields than the control. Of all the treatments ammonium sulphate showed consistently high yields in all the years.

SUMMARY

The results of the investigation presented in this paper, conclusively indicate that ammonium nitrate alone or admixed with T. N. T. is as effective a fertilizer as ammonium sulphate as found from the yields of major field crops like sorghum, wheat, maize, cotton and paddy. In most of the cases, significantly higher yields have been obtained by the application of different fertilizer treatments than that of control. The presence of T. N. T. in proportions of 1, 2, and 3 per cent in ammonium nitrate had no deleterious effect on the crop.

The results reported above were obtained under the Delhi and Karnal conditions where the *p*H of the soil are 7·3 and 8·1 respectively. The annual rainfall varied from 20 to 28·7 inches at New Delhi and from 21·5 to 32·2 inches at Karnal. All the crops were grown under irrigation.

ACKNOWLEDGEMENT

Our thanks are due to Mr. C. H. Parr, the then Head of the Division of Agronomy, under whose guidance the experiment was conducted, and to Mr. R. S. Gupta for the help rendered in the conduct of the experiment at Karnal.

REFERENCES

Borden, R. J. (1935). Sources of nitrogen : anhydrous ammonia *versus* ammonium sulphate *versus* ammonium nitrate. *Hawaii Plant Rec.*, **39**, 198-199

Fitts, J. W. (1945). Nebrasca Soil studies. *Comm. Ferti.* May 24

Paden, W. R. (1939). Effect of nitrogen from various sources upon the yields of seed cotton on unlimed and limed soils. *South Carolina Agric. Expt. Station. Rept.* 34

Skinner, J. J. and Buie, T. S. (1926). Sources of ammonia. *South Carolina Agric. Expt. Sta.* Bull. 227

Skinner, J. J. (1944). Ammonium nitrate as a fertilizer for cotton. *Comm. Ferti.* Feb. 48

Skinner, J. J., Williams, C. B. and Mann, H. B. (1929). Effects of synthetic nitrogen and concentrated fertilizers on cotton and sweet potatoes. *N. Carolina Agric. Expt. Sta.* Bull. 266

THE INFLUENCE OF SOWING DATES ON THE YIELD OF *OLEIFEROUS BRASSICAE* CROPS

By M. V. VACHHANI*

(Received for publication on 12 November, 1951)

(With one text-figure)

THE *Oleiferous brassicae* crops consisting of *toria* (*B. Campestris L.* var *toria*), *sarson* (*B. Campestris L.* var-*sarson*), *rai* (*B. juncea*) and brassicae substitute *taramira* (*Eruca sativa*) occupy about six million acres annually in India (undivided) and are chiefly confined to the Indo-Gangetic alluvium. They are sown solely as *rabi* season crops. These crops play a special role under the canal irrigated cropping system as due to their wide range of sowing, the irrigation water could be fully and economically utilized. Wheat which is the major *rabi* crop in Northern India has a limited period of sowing which ranges from mid-October-November. The crop sown earlier and later than this does not give an economic return as the earlier sown crop is liable to frost damage (which occur quite frequently in Northern India) and the late sown crop is affected by rusts. Therefore these brassicae oil seed crops could be profitably grown as supplementary crops to wheat and sown in advance of and after wheat sowings thereby raising the *rabi* intensity of cropping. Besides, these oil-seed crops thrive well on a wide range of soil types and pressure on the farm labour is well distributed.

With a view to have the precise information on the suitable time of sowing of the various brassicae oil-seed crops, an experiment was conducted at the Agricultural Research Station Dokri (Sind), over a period of three years 1942-43 to 1945-46 and the results are summarised in the present paper.

MATERIAL AND METHODS

The experiment was laid out according to split plot design with sowing dates as main plots and varieties as sub-plots to facilitate agricultural operations.

Each treatment was replicated four times giving a total of 96 unit plots, each measuirng 34 ft. × 14 ft. or about 1/80th acre in area.

I. *Sowing dates*—Four

S_1—End September | S_2—Mid-October
S_3—Early November | S_4—Early December

II. *Brassicae types*—Six

A. *Toria*—(Kazi Ahmed) | B. *Torio*—(Dokri)
C. *Sarson*—Yellow (Bengal) | D. *Sarson* black—(Sakrand-1)
E. *Rai*-(Jhatpat) | F. *Taramira*—(Sakrand-1)

A brief description of the types is given below :

A. Toria (*Kazi Ahmed*). An early maturing type taking about 100 days to be ready for harvest and requires only 1-2 irrigations. Plant is medium in height,

* Present address—Agronomist, Central Rice Research Institute, Cuttack, Orissa.

dichotomously branched with long cylindrical silique having brown seeds with oil contents of 38-42 per cent. It is self-incompatible in nature.

B. Toria (*Dokri*). It matures about 4-5 days later than *toria Kazi, Ahmed*, in other characters it is similar to that.

C. Sarson *Yellow* (*Bengal*). It is of medium maturity and very susceptible to aphids. Medium in height, the siliques are 1½-2½ in. long with short slender beak containing yellow seeds having oil contents of 36-38 per cent. It is self-fertile in nature.

D. Sarson *brown* (*Sakrand-1*). It is medium in maturity taking about 120 days to be ready for harvest. It branches profusely with medium cylinderical silique having brown seeds with oil content of 36-38 per cent. It is self-incompatible in nature.

E. Rai (*Jhatpat*). It is of medium maturity, tall growing with spreading branches having short, slightly compressed silique containing brown seeds with oil content of 33-36 per cent. It is self-fertile in nature.

F. Taramira (*Sakrand-1*). It is a brassicae substitute, late maturing and low yielder. But it is hardy and can stand adverse climatic and soil conditions and is more tolerant to salinity. It has oil content of 25-28 per cent.

Analysis of data and discussion of results

The crop during the year 1944-45 was badly damaged by aphids (*Aphids brassicae*) due to which the last two sowings gave practically no yield, hence that data has been eliminated and the results of two years. viz., 1943-44 and 1945-46 have been statistically analysed. The analysis of variance of the yield for both the years separately is shown in Table I. The value of variances have been so arranged that variances due to each of them can be tested for significance against their appropriate error variance.

TABLE I

Analysis of variance (yield of grain in lb.)

	D.F.	Variance	
		1943-44	1945-46
Blocks	3	13·87	5·94
Sowing dates	3	323·13**	107·92**
Error (a)	9	9·01	8·47
Varieties	5	158·89**	32·40**
Varieties × sowing dates	15	14·01*	9·38
Error (b)	60	7·13	6·52

*Exceeds the 5 per cent level of significance
**Exceeds the 1 per cent level of significance

From Table I it is apparent that the yield differences between dates of sowings and also between various varieties are significant. The interaction between the sowing dates and the varieties is found to be significant only during the year 1943-44 at 5 per cent level.

The mean yields per unit bed along with the S. E. are given in Table II. The L. S. D. value given in the table is the least significant difference between means, necessary to give odds of 19 : 1 that a difference as great as the L.S.D. value would be obtained by chance alone.

TABLE II

Mean yields in lb. per unit bed

Varieties		Sowing dates				Mean varieties	S.E.	L.S.D.	REMARKS
		S1	S2	S3	S4				
Year 1943-44	A	13·45	10·88	10·73	2·60	9·42	·66	1·79	E.B.A.D.C.F.
	B	16·63	10·55	10·18	3·83	10·30			
	C	9·00	8·83	8·10	0·95	6·72			
	D	7·85	8·23	5·00	1·60	5·67			
	E	15·55	12·55	10·58	4·10	10·69			
	F	3·60	3·08	2·18	1·52	2·59			
	Mean	11·01	9·02	7·79	2·43	7·57			
S. E. (date of sowing)		·62	(L.S.D. for the difference of two variety mean within a sowing date=3·58).						
	L. S. D. 1·864								
Year 1945-46	A	8·09	8·35	4·36	1·25	5·51	·737	1·80	E.B.A.D.C.F
	B	8·59	7·79	4·33	2·10	5·70			
	C	4·58	4·88	5·03	1·45	3·99			
	D	7·43	5·19	5·08	1·30	4·70			
	E	11·75	6·86	6·14	4·86	7·40			
	F	3·72	2·94	3·92	2·91	3·37			
	Mean	7·29	6·01	4·81	2·31	5·10			
S.E. (date of sowing)		·50	(L.S.D. for the difference between two variety means within a sowing date=3·6)						
L.S.D.		1·886							

The above results indicate that the yield of all the varieties are greater for the early sowings and decline progressively with advance date of sowing. There is significant difference between the mean yields of varieties and they could be roughly put in two groups, viz., the high yielding and the low yielding groups. Varieties A, B and E fall in the first and varieties C, D and F in the later group. The superiority of the varieties in the first group is maintained in all sowing dates and for both the seasons, although the differences of this group with the low yielding group tend to get smaller with advancing sowing dates. It may be noted that the large portion of the S. S. due to varieties is contributed by the difference between these two groups the difference within each group not being significant. Thus during the year 1943-1944, from the total S. S. of 794·4 belonging to varieties, the S. S. for one degree of freedom for two groups is $\frac{(\overline{E+B+A}-\overline{C+D+F})^2}{6\times k} = \frac{(486{\cdot}4-239{\cdot}8)^2}{6\times 16} = 633{\cdot}45$

where A,B,C, etc., denote the total yield of corresponding varieteis and K number of plots. Similarly during the year 1945-46, from the total S. S. of 161·98 belonging to varieties the major portion of 109·96 is due to group differences.

It is apparent from Fig. 1. (yield sowing date curve) that advanced sowing dates have decreased the yield considerably. The S. S. for sowing dates is partitioned into its individual components and the results are presented in Table III.

TABLE III

Splitting up of S. S. for sowing dates into its components

	D.F.	Variance	
		1943-44	1945-46
Linear component	1	873·45	312·3
Quadratic component	1	67·65	8·90
Cubic component	1	28·76	2·32
Error	9	9·01	8·47

For testing of trends, the variances for each single degree of freedom are compared with the appropriate error variance and it is found that linear trend is significant in both the years while quadratic component is significant in one year only. It may be noted that the linear component is the average change in the yield for sowing dates, while the quadratic component is the average change in linear component. Thus not only there is fall in yield with the advanced sowing dates, but the rate of fall is not uniform, it being very large after early November sowings.

However the main object of the investigation is to find out the best variety or varieties for a given sowing date. From Table II it is seen that variety E, B, A maintain their superiority over other three varieties in each sowing date during both

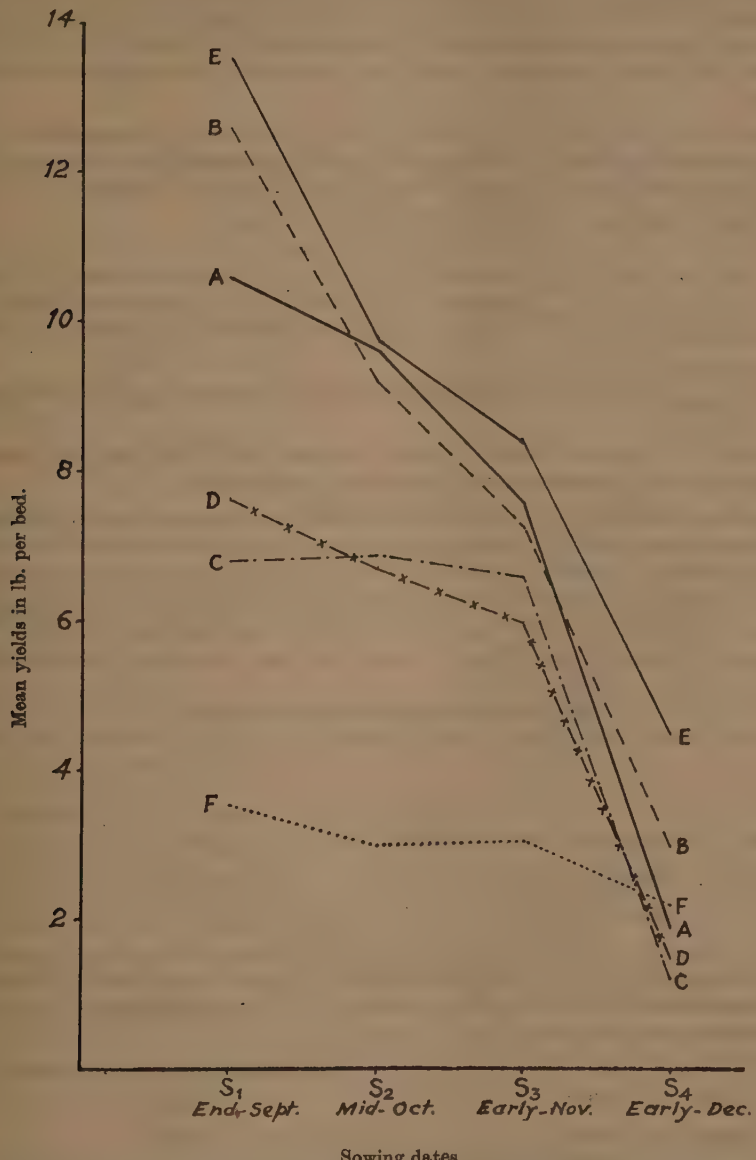


FIG. 1. Yield-sowing date curves for different brassicae types for the average of two seasons 1943-44 and 1945-46

the seasons though there are wide differences in yield between the two seasons, second season (1945-46) being a poor one. The yield differences between E, B, A being not significant, the selection among them is optional, but there is an indication that variety E is better, especially under late sowings and also responds better in poor season.

It may incidentally be noted that the sowing date-variety interaction S. S. is mainly contributed by one *d. f.* corresponding to the interaction of the linear component of sowing date with differences between two groups of varieties. The S. S. corresponding to this one *d. f.* can be symbolically written as :

$$\frac{\left\{(V_1-V_2)(3S_4-S_3-S_2-3S_1)\right\}^2}{4\,(54+6+6+54)}$$

where $V_1\,S_i$ and $V_2\,S_i$ denote the total of variety groups A, B, E and C, D, F respectively for the ith sowing. The corresponding figure for the season 1943-44 is $\frac{(-215{\cdot}2)^2}{4\times 120}=96{\cdot}48$ which is significant at 1 per cent level. The significance of this S. S. indicates that difference between the high and low yielding variety groups rapidly decreases with advancing sowing dates.

The combined analysis. The yields during both the seasons are widely different, the mean yields being 605 lb. and 408 lb. per acre during the seasons 1943-44 and 1945-46 respectively. The data of two years may be pooled up and a single analysis worked out, provided the error variances for both the seasons are homogenous. The comparison of the corresponding errors for the two seasons is given below. The residual error per cent of the mean for both the years have been calculated and presented.

Residual errors as percentage of the mean

	Years	
	1943-44	1945-46
Error a	39·5	55·9
Error b	35·1	49·1

The homogeneity of the residual errors can be tested in this case by F test as only two seasons are involved. The comparison of the corresponding errors for the two seasons are given below.

	F	*Significant F at 5 per cent.*
Error a	1·06	3·18
Error b	1·09	1·52

Since the corresponding variances show no significant differences for the two seasons, the data can be pooled and a combined analysis given.

Accordingly the pooled analysis of variance has been worked out and presented in Table IV and the mean yields of various types for different sowing dates are graphically represented in Fig. 1.

TABLE IV

Combined analysis of variance (1943-44 and 1945-46)

		D.F.	S.S.	Variance	F.
Blocks		6	59·30	9·88	..
Seasons		1	290·10	290·10	33·4**
Sowing dates	Linear component	1	1114·56	1114·56	128·40**
	Quadratic component	1	63·02	63·02	7·26*
	Cubic component	1	23·69	23·69	·273
	Total	3	1201·27	400·42	46·1**
Sowing dates x seasons		3	91·62	30·54	3·5*
Error (*a*)		18	156·30	8·68	..
Varieties		5	792·05	158·41	23·2**
Varieties × seasons		5	164·19	32·84	4·8**
Varieties × sowing dates		15	261·65	17·44	2·5**
Varieties × sowing dates × seasons		15	89·00	3·93	..
Error (*b*)		120	820·28	6·84	..

The combined analysis brings out the effect of seasons and the interactions of other factors with season. The pooled yield differences on account of varieties, sowing dates and their interactions are significant confirming the conclusions of the individual seasons. Seasonal effect is highly significant and also the interactions of seasons × sowing dates and seasons × varieties, indicating that the brassicae crops are very much influenced by the seasonal variation. It may be noted that the difference among sowing dates is less in poor season and so also the verietal difference. Since the present data pertain only to two seasons it is not possible to ascertain the influence of weather conditions on the yield but nontheless it points out to the need of conducting experiments over a number of years to study this aspect.

Since in the combined analysis, the linear and quadratic components of sowing dates are significant, the second degree polymonial can be fitted to the curve to get a functional relationship of the yield with sowing date. The regression for the second degree ploymonial is given by $Y=A^1+B^1\ (X-\bar{X})+C^1\ (X-\bar{X}),^2$ where

Y=yield and X=sowing date. The value of the constants obtained are given below along with their appropriate standard errors.

$$A^1 = 7{\cdot}05 \pm 0{\cdot}340$$

$$B^1 = -2{\cdot}160 \pm 0{\cdot}482$$

$$C^1 = -0{\cdot}570 \pm 0{\cdot}755$$

Therefore the value of $Y = 7{\cdot}05 - 2{\cdot}16(X - 2{\cdot}50) - {\cdot}570(X - 2{\cdot}50)^2$

The estimated values for various sowing dates along with the observed values are given below :

X—	S1	S2	S3	S4
Y—Yield per unit bed in lb.				
Estimated	9·008	7·987	5·828	2·527
Observed	9·16	7·51	6·30	2·36

Based on the above results the mean yield-sowing date relation can be adequately represented by the polymonial of the second degree.

Summary

The effect of sowing dates on the yield of various oleiferous brassicae crops has been studied.

Rai and two varieties of *toria* give significantly higher yield than yellow and brown *sarson* and *taramira*.

The yields of all the varieties decrease with the advancing sowing dates, the fall being rapid after early November.

Amongst the high yielding varieties *rai* (*Jhatpat*) gives higher mean yield in all sowings, especially in late sowings and can better stand the adverse climatic conditions, though the differences are not quite significant.

It is advantageous to plant either variety of *toria* during the months of September-October and *rai* during the months of November-December.

The functional relation of yield and sowing date can be adequately represented by the second degree polymonial.

Acknowledgments

The author expresses his thanks to Rai Bahadur R. L. Sethi the then Director of Agriculture, Sind and now Agricultural Commissioner with the Government of India and Mr. K. Ramiah, Director and Mr. T. P. Abraham, Statistician, Central Rice Research Institute for their valuable suggestions in compiling up the data and writing up the manuscript.

REFERENCES

Annual Reports, Department of Agriculture, Sind, Karachi

Fisher, R. A. (1938). *Statistical methods for research workers*, Ed. 7, Oliver & Boyd, London

Senedecor, G. W. (1940). *Statistical methods*, Ed. 3, Iowa State College, Press, Ames Iowa

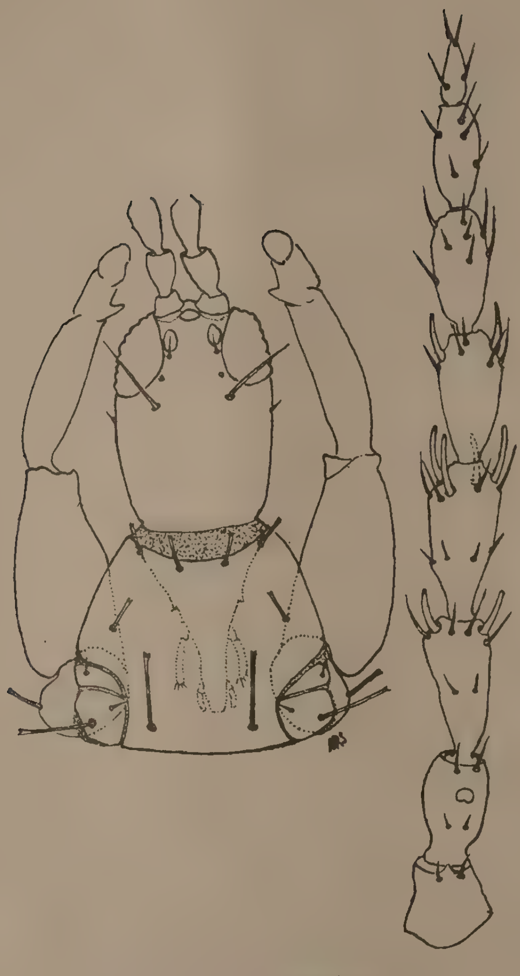


FIG. 1. *Dolichotrips assimilis* sp. n.
(*a*) Female, head and prothorax
(*b*) „ left antenna

SOME NEW THYSANOPTERA FROM SOUTH INDIA

By H. Priesner, Lately Entomologist, Ministry of Agriculture, Cairo, Egypt and A. R. Seshadri, M.A., Assistant Entomologist, Agricultural College and Research Institute, Coimbatore, South India

(Received for publication on 24 October, 1951)

(With Plates XXXII-XXXIV)

Dolichothrips assimilis spec. nov.

Plate XXXII

FEMALE. Black, fore tibiae yellowish towards apex or brownish yellow, margins and base dark, fore tarsi yellow, middle and hind tarsi greyish yellow. Antennal joints 1, 2 and 8 dark, 3 to 6 pale yellow, 7 greyish at apex. Wings hyaline, basal bristles and all major body bristles blackish, anal setae paler towards tips.

Head length ab. 240, width across eyes 212-216, cheeks narrowed towards base, strongly constricted near base ; lateral diameter of eyes 87 ; rostrum long, slender, strongly pointed, sides concave, length from hind margin of head 173-182. Postocular bristles not more than 56, placed well inward. *Antennae,* measurements of joints : 16 (base 32, apex 24), 48-52(28), 64(28), 62(32), 52(28), 50(24), 44-48(22), 28(10-11). Joint 3 with two, 4 with four sense-cones, 8 somewhat narrowed at base, 3 somewhat asymmetrical. *Prothorax*, length 176-180, width (without coxae) 260 ; antero-angular bristles developed, blunt, 40-45, interior antero-marginals similar ; postero-marginals and epimerals with blunt, white tip, 72-80 long. *Fore femora* incrassate, fore tarsi with triangular tooth. *Pterothorax*, width ab. 363. *Wings*, length 950, much broader at base than apically, narrowed at middle, basal bristles 64, 60 and 88-92, blackish ; 9-12 cilia duplicated. *Abdomen* tapering towards apex, with long, dark, blunt lateral bristles, of which those on segment VIII measure 68-72 and 88 ; bristles on segment IX, b.1 : 200-212, b.2 : 184-196, all pointed. *Tube* short, conical, length 148-160, width at base 74-76, at apex 36. Anal setae, length ab. 180. (All measurements in microns).

Male. More slender than the female. General pattern of coloration as in female, but a little paler ; joint 7 of antenna uniformly greyish. Fore femora and tarsal teeth somewhat weaker. Bristles 1 and 2 of abd. seg. IX more or less equally developed as in the female. Wings with 8-10 duplicated cilia.

Measurements of male (Allotype) : Head, length 226, breadth across eyes 157, lateral diameter of eyes 60, rostrum as in female 148, postocular bristles 36. Antennal joints, 31 (base 32, apex, 24), 46(26), 61(26), 63(27), 56(24), 51(22), 44(19), 29(12). Prothorax length 148, width without coxae 244. Pterothorax length 348, width 313 ; wings length 783, basal bristles 41, 44 and 42. Bristles on seg. IX of abdomen, b. 1 : 143, b. 2 : 129 ; tube width at base 61, at apex 34. Anal setae about 145. (measurements in microns).

Habitat. Several individuals of both sexes, South India, Valparai, 4. IX, 1945, in flowers of *Macaranga indica* (leg. E. R. G. Menon ; coll. Seshadri no. S. 12).

Types in the Entomology Section of the Agricultural College and Research Institute, Coimbatore (S. India) and in the Zoological Survey of India, Calcutta.

This species, belonging to the subgenus *Dolichothrips* s. str., comes very close to *D. longicollis* Karny, and may thus be easily confused with it. It differs specifically by its much shorter head (in *longicollis*, length 260-295) and rostrum (in *longicollis* 277-295), by the somewhat shorter antennae, but it has somewhat longer or equally long bristles on abdominal segment IX. Other species of this genus have either all tibiae yellow, or are characterized by the absence of double fringe hairs, or (subgenus *Dolicholepta*) have simple fore legs or pale body bristles.

Leeuwenia maculans spec. nov.

Plate XXXIII

Female. Brown to dark brown, margins of head and thorax sometimes somewhat darker, abdominal segments may be lighter at hind, and darker at fore, margins, insertions of dorsi-ventral muscles indicated by yellow spots. Antennal joints 1, 2 and 8 dark, 2 mostly pale at exterior margin, 3 to 7 pale yellow. Legs with coxae and femora dark, tibiae and tarsi pale yellow, fore tibiae slightly shaded with brown at base, middle and hind tibiae distinctly darkened in basal third, or more extensively. All major bristles deep yellow. Wings hyaline, both with yellow-brown longitudinal vein, the latter being approximated to hind margin in fore wing, and fading out in apical fourth or so ; fringe dark.

Head elongate, widened towards base, with distinct notch behind eyes, cheeks set with small spine-bearing warts that are more conspicuous in front than towards base of head. Surface of vertex, behind ocelli, polygonally reticulated, but transversally so, behind. Head somewhat produced in front, production 44 long, 126 broad ; length of head from eyes, 380, total length 415 (476 in the paratype), width across eyes 220, across cheeks near base 300 ; vertex set with several irregularly placed small bristles, postoculars wanting. Front ocellus situated on cephalic production, hind ocelli in anterior third of eyes ; ocellar triangle somewhat elongate, equilateral. Dorsal length of eyes 140, lateral length 124. Mouth-cone very broadly rounded, little surpassing middle of prosternum. *Antennae*, total length 675 (in the paratype 718) ; measurements of joints : 44 (base 52, apex 48), 68-72(40), 128(32-33), 110(36), 116(36), 96(34), 68-72(26), 50 (16). Joint one little narrowed towards apex, 2 scarcely constricted near base, 3 elongate, with slight convexity before middle, concave beyond middle, sense-cones fine, one on 3, two on 4. *Prothorax*, length 225, width without coxae 415-433 ; all bristles very small, except epimerals, which are 52 long, pointed. Epimeron not well separated from pronotum. *Pterothorax* broader than long, width 657. Coxae widely separated, those of middle legs 346, those of hind legs 450, distant. *Wings*, length 1384, narrow, without double fringe cilia, basal bristles very small, placed in a straight line, far apart from one another, length 20-30. *Abdomen* narrowed towards apex, lateral bristles short, those on segment VII : 116, those on VIII : 92 ; bristles on segment IX stout, rather sharp, length 76-88. *Tube* very long and slender, length 1557 (in the paratype 1730), width at base 124, at middle 84-88, at apex 60 ; sides furnished

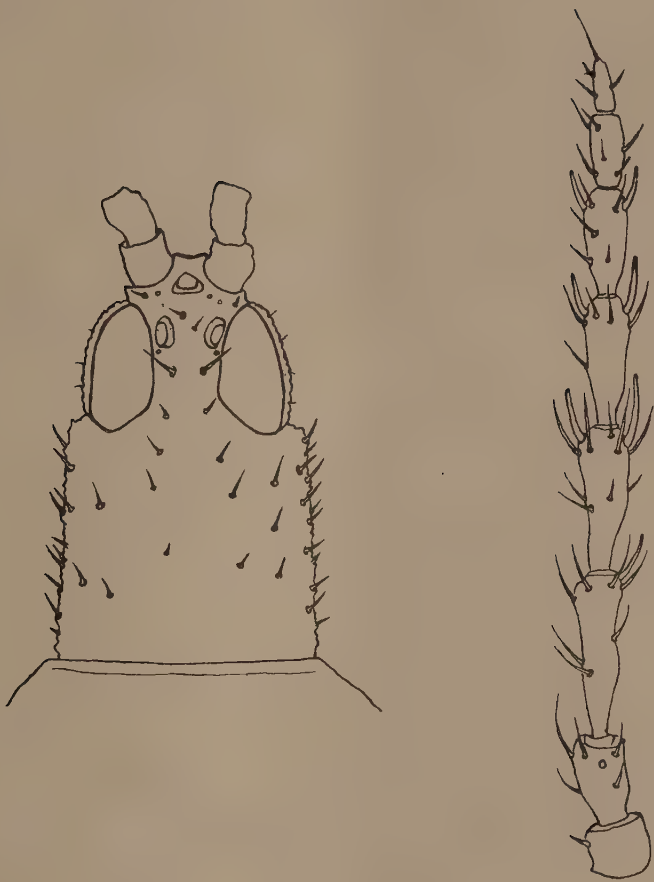


FIG. 2. *Leeuwenia maculans* sp. n.

(*a*) Female, head

(*b*) ,, right antenna

(up to apical fourth) with little-raised setae that are shorter (52-60) than the width of the tube about middle. Hind tibiae, length 380. Anal setae short, 220.

Male : Nearly identical with the female in every respect.

Measurements of male (Allotype). Head, length from eyes 348, width across eyes 200, across cheeks near base 235, length of production in front of eyes 35-44, breadth 104—113 ; dorsal length of eyes 113, lateral length 96 ; Antenna total length 661, measurements of joints, 48 (base 50, apex 44), 68(37), 126(32), 109(36), 111(34), 84(31), 58(23), 44(17). Prothorax length 226, width without coxae 374, epimeral bristle 54. Pterothorax width 618, distance between coxae of middle legs 466, of hind legs 278 ; wings length 1305, basal bristles 17—24. Lateral bristles of abd. seg. VII, 90, of VIII, 68, and of IX, 80 ; tube length 1488, width at base 102, at middle 73 and at apex 53 ; anal setae 170. (All measurements in microns.)

Habitat. Ten females and 5 males, South India, Singampatti, 28. IV, 1949, on leaves of Cardamom, leg. A. R. Seshadri (no. S. 96). Types in the Entomology Section of the Agricultural College and Research Institute, Coimbatore (S. India) and in the Zoological Survey of India, Calcutta.

In this species, the lateral tube setae are rather short and nearly attached, i.e., only slightly raised, the postocular bristles wanting ; it has to be compared with *L. spinosa* Moult. and *L. eugeniae* Bagn. The new species is, however, characterised by its exceptionally long tube, which is much more than three times as long as the total length of the head.

Larva, II. stage. Typical for the genus, with segments IX and X of abdomen very long. Pale yellow, with a few (1-3) large, crimson pigment cells in the metathorax. Grey shadings very pale, cephalic plates quite indistinct, prothorax without plates, segment IX of abdomen shaded only at apical margin, segments X and XI dark, but brownish yellow in basal half, very slightly shaded with grey. Antennal joint 1 light, 2 only at base darker, 3-5 pale yellow, or 5 slightly infumated, 6 and 7 grey.

Head, width across eyes 148-160, strongly widened towards base ; the three pairs of cephalic bristles (one of them behind eyes) pointed, curved. Antennae elongate, much longer than in either *L. seriatrix* or *gladiatrix*, 3 very slender, 4 and 5 elongate, conical, 6 and 7 fused. Bristles 1 and 2 on prothorax pointed, ab. 48, b. 3 knobbed, 84-88, b. 4 and 5 knobbed, 80-87, b.6 knobbed, ab. 108, b. 7 fine, slightly knobbed, 80. On meso- and metathorax, the bristles of the anterior row are not or slightly, those of the posterior row distinctly, knobbed. Abdomen slender, strongly tapering posteriorly, b.1 and 2 slightly knobbed, b.3 pointed, on segment VIII, b. 1 : 80, b. 2 : ab. 92 long. Bristles on IX much longer, but varying in length, b. 1 and 2(e.g.) 120-128, knobbed, b. 3 : ab. 140, pointed. Segment IX, length in large specimens 216, basal width 132 ; segment X, length ab. 304, width at base 78-84, at apex 40-45. Anal setae well 160 long (Measurements in microns).

Praepodothrips gen. nov.

Antennae 8-segmented, slender, joint 8 slender, narrower than 7 at apex, and usually slightly constricted at base ; joint 4 with only two sense-cones. *Body*

depressed. *Head*, large, oval, longer than broad, broadest behind eyes, cheeks strongly and evenly convex, interantennal projection broad, truncate in front; eyes truncate at hind margin, outline, therefore, about triangular; eyes not at all protruding. One pair of postocular bristles present, situated very close to lateral margin of vertex. Mouth-cone *very* short, broadly rounded. *Prothorax* somewhat broader than head, sides much widened towards base, epimera separated, posterior margin of prothorax strongly convex, fore margin nearly straight, antero-marginal bristles vestigial, epimerals and interiors at hind margin well developed. *Fore legs* of female not or scarcely enlarged, those of male distinctly so, fore tibiae entirely simple, without tooth or tubercle, but pointed interiorly at tip, fore tarsi toothed in both sexes, tooth normal, not as in *Watsoniella* or *Plagiothrips*. *Pterothorax* elongate, parallel-sided. *Wings* distinctly haplothripoid, narrow, fringe not dense, double fringe developed. *Abdomen* haplothripoid, with long lateral bristles. *Tube* short, conical, with slight constriction beyond base, particularly in the male. Anal hairs long. Body bicoloured in the type species.

Typ. gen. *Praepodothrips indicus* Spec. nov.

Priesner's keys ("Gen. Thys., 1949") lead to *Haplothrips*, if one tries to identify this form by means of them. The depressed body, the shape of the head, the nearly triangular eyes, the very short, broadly rounded mouth-cone, the shape of the prothorax and antennae, the presence of only two sense-cones on joint 4 of the latter, approximate this new form to *Podothrips*. The new genus is distinguished from *Podothrips* by the absence of a tibial tooth or tubercle and the extremely weak antero-angular prothoracic bristles. One could consider the new type as a subgenus of *Podothrips*, but, since we have always treated tooth-like appendages of the tibiae as generic characters, we have to be consequent and consider the new form as a separate genus.

Praepodothrips *indicus* spec. nov.

Plate XXXIV

Female : Head, prothorax, pterothorax, and (VII) VIII—X abdominal segments dark brown, rest of abdomen orange or yellowish. Antennal joints 1, 2 (only at inner margin), and 8 brown, sometimes 7 slightly darkened at tip, remaining joints pale yellow. Legs pale brown or brown, tibiae paler at base and apex, fore femora more or less yellow at apex, in some cases legs wholly brownish yellow, only fore femora darkened at base, and the tibiae more or less at margins ; in some cases the hind femora are somewhat paler than the hind tibiae. Tarsi yellow. Wings nearly hyaline, or slightly shaded, always somewhat infumated at the narrow middle. Body bristles pale, anals darker.

Head from eyes 276 long, behind eyes 234 broad, interantennal projection straight in front, width 32 ; length of eyes, laterally, 96, cheeks behind them 180-188 ; cheeks distinctly and evenly convex ; hind ocelli broadly separated, situated in front of middle of eyes, anterior ocellus on interantennal projection. Postocular bristles close to sides of head, only 14-16 distant from them, length of pointed post-oculars 76. Mouth-cone very short, broadly rounded, labrum blunt. *Antennae*

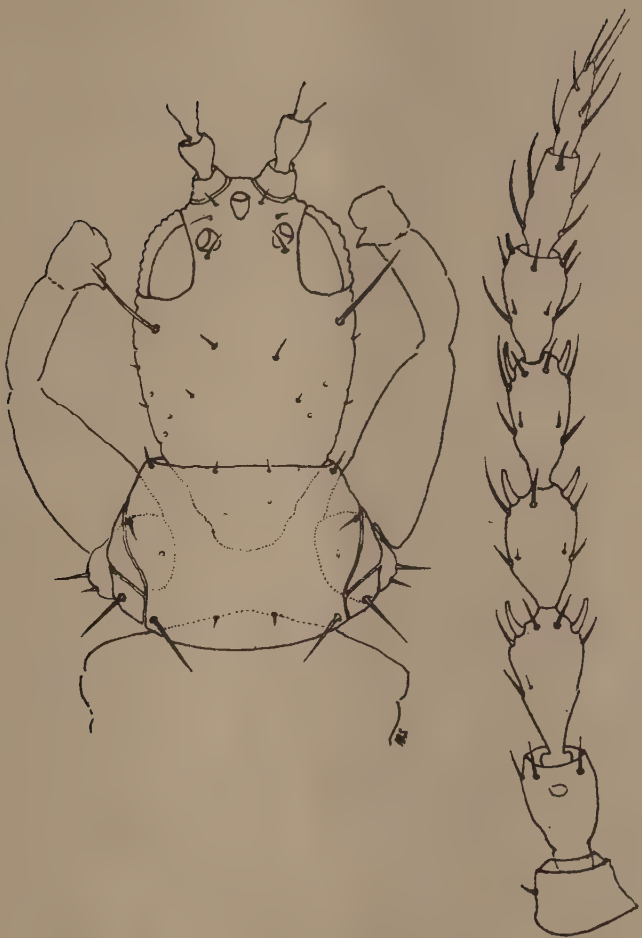


FIG. 3. *Praepodothrips indicus* g. et. sp. n.

(*a*) Female, head and prothorax

(*b*) ,, right antenna

moderately long, slender, joint 1 strongly narrowed towards apex, 3 asymmetrical, with two sense-cones, 4 also with two, 5 and 6 with two each (accessory sense-cones setiform), 7 with 1 dorsal sense-cone, joint 8 much narrower at base than 7 at apex, parallel-sided at base or slightly fusiform. Lengths (breadths) of joints: 25-28 (base 45, apex 31), 53-56(31), 56(29), 53(29), 55(27), 49(24), 49(20), 36(10); total length of antennae 380. *Prothorax*, length 200, width without coxae 284, with coxae 336. Bristles on fore margin vestigial, epimerals ab. 60, coxals 36-40, all pointed or nearly so. *Fore femora* scarcely incrassate, fore tibiae obliquely pointed at apex, fore tarsi with conspicuous triangular tooth. *Wings* narrow, fringe not dense, smooth, basal wing bristles short, in a straight line, nearly pointed, lengths 25, 36 and 32; 4—6 cilia duplicated (in both sexes). *Abdomen* normal, lateral bristles long, nearly straight, pointed up to segment VII (b:2, 120), bristles on segment VIII slightly knobbed, 88, on IX pointed, ab. 100. *Tube* conical, but sides not absolutely straight, length 156-160, width at base 74, at apex 28. Anal setae, length 232.

Male. Similar to female, but fore femora more strongly enlarged, tarsal tooth stout, triangular. Tube somewhat concave beyond base, apex constricted. Measurements: Head, length 252, width 204; lateral diameter of eyes 88. Post-ocular bristles, length 65. Antennal joints: 25-28 (base 39, apex 31), 50(28), 56(28), 50(27), 53(25), 46(22), 48(18), 39(11). Prothorax, length 180-185, width 260-270. Pterothorax, length 310, width 295. Bristles on segment IX, b. 1: 96-104, b. 2: 64 (stouter), b. 3: 88-96. Tube, length 140, width at base 64, at apex 29. Anal setae, length 200. (All measurements in microns.)

Habitat. Several individuals of both sexes, South India, Valparai, September 1945, host unknown, but most likely a *Gramineae* sp. (leg. E. R. G. Menon; coll. Seshadri No. S. 34). Types in the Entomology Section of the Agricultural College and Research Institute, Coimbatore and in the Zoological Survey of India, Calcutta.

Larva, II stage. Specimens on hand pale yellowish white due to long preservation, but must have been orange red as indicated by groups of pigment cells in a few specimens, especially in the thorax and the abdominal tip. Cephalic plates quite indistinct and prothorax without plates. Joints 4, 5, 6 and 7 of antennae and abd. segs. IX and X shaded with grey; transverse bands on seg. VIII feebly developed.

Head, width across eyes 95; cheeks convex, showing a tubercle-like prominence at its summit on each side. Antennae length 211; lengths (breadths) of joints, 20(31), 32(24), 34(26), 37(24), 31(20), 29(17), 34(10); joint 1 quite normal, 2 with the outer margin more convex than the inner, 3 somewhat barrel-shaped and broadest towards apex, 4 and 5 bell-shaped with the sides gradually tapering towards base, 6 more or less parallel sided, 7 normal. Post-ocular bristles 44, pointed. Prothoracic bristles not at all distinct and hence not correctly measurable except b. 4—7 which are 15, 20, 19 and 19 respectively. Pterothorax width 209. Abdominal seg. IX, length 63, breadth 73. Bristles b.2. on segs. II to VIII and b. 1. of seg. IX knobbed; those on VIII, b. 1: 27, b. 2: 37, and b.3: 48; seg. IX, b.1: 78, b. 2: 136.

Segment X, length 68, width at base 39, at apex 22, Anal setae very long and flagellate, ab. 357—360.

Mesicothrips plicans Priesner

Priesner, 1951, Indian Journal of Entomology, XIII, pp. 191—192.

Larva, II stage. Quite ordinary, of *Gynaikothrips* habitus. Yellow, with the usual dark cephalic and complete pronotal plates, the latter being elongate. Antennae shaded with grey. Thorax with only dot-like basal plates of the dorsal bristles, segment VIII of abdomen with transverse plate, segments IX to XI dark.

Head, width across eyes 132. Antennae, length 346. Lengths (breadths) of joints : 28(36), 44-48(28), 80(27), 56(29), 52(26), 40(21), 40(12) ; joints 1 and 2 parallel-sided, 3 slightly constricted at middle, 4 exteriorly at apex strongly convex, 4, 5 and 6 constricted beyond base, 6 and 7 sharply separated. Bristles on prothorax knobbed, b.1, 2 : 56-60, b.3 : 72-76, b. 4 : 88, b. 5 : 100, b. 6 : 112, b. 7 : 100-120. Mesothorax, width 502-536. Abdominal segment IX, length (width) 96 (104), segment X, length (width) 92 (base 76, apex 36) ; bristles on segment IX(1-3) knobbed, 92-96. Anal setae moderately long, ab.120. (All measurements in microns.)

Scelothrips menoni (Ananthakrishnan)

Synonyma : *Ischyrothrips menoni* Ananthakrishnan (♂), Indian Journal of Entomology, XI, pp. 9-10, 1950.

Scelothrips menoni Priesner (♀), Indian Journal of Entomology, XIII pp. 188—190, 1951.

The bulk of the collections referred to by Ananthakrishnan, 1950 [*loc. cit.*] happen to be in the Entomology Section, Agricultural College and Research Institute, Coimbatore and the synonymy indicated above is no matter of doubt at all. Fortunately the specific name remains unchanged, though independantly christened. We have in our possession numerous individuals of both sexes and it is obvious that the author has mistaken the sex of the couple of female specimens he had at his disposal and this has partially led to the incorrect identification of the genus as well. As has been emphasised by Priesner [1951, *loc. cit.*], the genus *Scelothrips* is characterised by 'the exceptionally strong, incrassate fore legs of the female, the exceptionally long, straight trasal tooth, the *weak development of these organs in the male sex*, the sulcate interantennal projection of the female, the roughened cheeks, the cephalic angles (behind eyes), the elongate antennae and the evenly wide broad wings. As such, the characterisation given by Ananth akrishnan becomes inadequate.

Incidentally a few inaccuracies in the description may also be pointed out here. The coloration of the middle and hind tibiae, the exaggerated measurements of the head, the relative lengths of the eyes to the head and of the abdomen to the rest of the body etc. are instances on the point. The fore tibia does not show any blunt tooth, but its widened and pointed tip has been mistaken for one, another factor which has led to the identification as an *Ischyrothrips*. As already mentioned, the

extremely well developed tarsal tooth is a distinguishing feature of the female, fore leg and not of the male. Such specific details as the measurements of the eyes cephalic and prothoracic bristles, the sense-cones of the antennae, the sulcate inter-antennal projection, the striations and reticulations of the head and prothorax etc., have not been mentioned at all, much less indicated in the figures given.

Larva, II. stage. Yellow ; cephalic plates, two pronotal plates, separated by a fine pale line, very indistinct basal dots on thoracic insertions of bristles, and the whole segments IX to XI dark. Femora somewhat shaded with grey, tibiae only basally shaded. Antennal joints 1, 2 and 5 to 7 grey brown, 3 pale yellow, 4 transitional in colour.

Head, width across eyes 140-165. Antennae, length 346-363 ; lengths (breadths) of joints : 32(44), 52(32-33), 84(34), 68-72(33), 56(30), 46(25), 32(14) ; joint 3 quite normal, 4 to 6 little constricted beyond base, 6 and 7 fused or separated by an incomplete suture. All prothoracic bristles hair-like, pointed, curved, not easily measurable, b.6 about 220 long, b. 7 : 100. Bristles on meso and metathorax and abdominal segment I pointed, on segments II to VII b. 1 and 2 knobbed, b. 3 pointed, on segment VIII all three pairs knobbed, b. 2 on VIII well 120 ; all these bristles strongly curved. Bristles 1—3 on segment IX knobbed, strongly curved, 120-128 long. Segment IX, length 120, basal width 132, segment X, length 120, basal width 87. Width of thorax in most specimens (fullgrown) 692-760. Anal setae, length 180.

Larva, I. stage : Very difficult to characterize, normal, all body bristles pointed, only b. 1 on segment IX of abdomen knobbed. B. 6 on pronotum ab. 144, b. 4 : 92, b. 5 : 80. B. 1 on segment IX ab. 140. Segment IX, length 28, width 72, segment X, length 62, width 48. (All measurements in microns.)

The prepupae and pupae are quite normal.

Indusiothrips seshadrii Priesner

Priesner, 1951, Indian Journal of Entomology, XIII, pp. 183-185.

Larva, II. stage : Body pigment and eyes pale crimson. Legs hyaline, antennae slightly shaded with grey, joints 5 and 6 more strongly sclerotized, brown. Body without infumations and without dorsal plates.

Body bristles extremely short, blunt, hyaline. Head, width across eyes 80-85. Thorax, width ab. 225. Antennal joints, lengths (breadths) : 20(27), 28-31(24), 42-45(25), 62-64(25), 13(11), 21(7). Posteroangular prothoracic bristle not more than 3 long. Abdomen with transversal rows of pale, rounded warts, without microtrichia. Longest bristles on segment VIII of abdomen, 8, somewhat curved, blunt. Bristles 1 and 2 of segment IX blunt, 16-18 long ; Segment IX, width 92-108, segment X, width 58. Bristles on segment X fine, hair-like, curved inward, shorter than the segment, (Measurements in microns).

REVIEWS

BOTANY OF SUGARCANE

By C. van Dillewijn

(*Published by the Chronica Botanica Co., Waltham, Mass, U.S.A,. Macmillan & Co., Ltd., Calcutta, Crown 8vo, pp. 371+xxiii. 1952, Price $6.00*)

THIS excellent book fills a real lacuna in sugarcane literature and meets a long felt want and should be useful alike to the cane grower and the scientific worker. Dr C. van Dillewijn has accomplished a difficult task with credit. The vast and scattered information on the morphology, anatomy and physiology of sugarcane has been very well collated and presented in a readable form.

The author states in the preface that his aim is only to give an inventory of our present knowledge on the subject, but he has rightly gone well beyond this modestly professed objective. He has not merely given a good survey of the known botanical facts in a well connected and properly classified manner, but has also presented the fundamentals in terms of their practical possibilities and limitations. This is particularly useful to the young student of sugarcane as his outlook would thereby be moulded along rational lines. At the same time the author has not digressed into related subjects or involved the reader into any abstruse discussions and has erred, if at all, on the side of brevity.

The book is divided into two sections. The first deals with the morphology and anatomy of the sugarcane plant. The second and much larger section is devoted rather exhaustively to the physiology of the cane plant and covers chapters on germination, tillering, growth, chemical and vegetative composition, nutrition, water-relationships, photosynthesis and respiration. The subject matter is arranged as a logical progression of ideas and has been presented with commendable clarity. Figures and tables have been judiciously selected and references to recent research work, which have been relatively inaccessible, contribute considerably to the value of the book.

In a book on the botany of sugarcane one would have expected that the important work on the taxonomic, cytological and genetical aspects of sugarcane would be included. Another glaring omission is the non-inclusion of work on the physiology of flowering in sugarcane. Perhaps these subjects are proposed to be discussed in a separate book. The volume is very attractively got up and some 3 or 4 errors notwithstanding, the printing is excellent. As it will be widely used as a reference book, the addition of an author index with reference to the text pages will be useful and may be included in the next edition. The bibliographical reference to paper No. 555 is incomplete.

Presenting as it does in a readily available and assimilable form the literature which would otherwise consume years to collect and study as individual papers,

Dr van Dillewijn's book is bound to help a great deal in future research work. In India in particular with its continental size and far flung research stations where the average research worker is seriously handicapped by inaccessibility of scientific literature Dr van Dillewijn's book will be found to be of especial value. One can unhesitatingly recommend that every agricultural and botanical research worker on sugarcane and particularly the young workers should possess a copy of this book and acquaint themselves with its informative contents. (N.L.D.).

MOISTURE REQUIREMENTS IN AGRICULTURE

By HARRY BURGESS ROE

(*Published by McGraw-Hill Book Company Inc. 1950, pp. 413, price $5.50*)

THE book meets the need of a general purpose text, viewing the whole aspect of irrigation farming for students and teachers. It is well written. The diagrams pictures and charts are excellent. The illustrative examples at the end of many chapters and the list of problems for the student to work out are definitely of great help. The inclusion of a brief summary of the essential soil properties to be considered in land-use planning with the symbolization and accompanying explanations in chapter 1, of an account of main essentials of the practice of water spreading in the chapter on disposition of soil moisture and of the outline of the empirical method on consumptive use determination in the chapter dealing with use of water in irrigation are very helpful. Tables 40 and 41 give very useful data on approximate average total annual water requirement of crops for Western U. S. A. A separate chapter on supplemental irrigation is a welcome feature. The list of references is well chosen.

Since accurate measurement of ' head ' in water measuring devices dealt with in chapter 3 is so important, a paragraph on guages would have been appropriate. While dealing with soil moisture determination a little discussion on the various methods for their determination *in situ* would be welcome. Though it has been said there is not much choice as between night and day irrigation the former in this country has definitely been found to lead to wasteful use of water. The system of rice cultivation in California today is different from what has been given. (N.P.D.)

ECONOMIC SURVEY OF ASIA AND THE FAR EAST 1950

(*Published by United Nations, Lake Success, N. Y., U.S.A. 1951, Price $3, 75, pp. xxiv+541, available from Oxford Book & Stationery Co., Scindia House, New Delhi, India*)

THE *Survey*, prepared by the Economic Commission for Asia and the Far East with the help of the Governments of the ECAFE countries and Japan and various Specialised Agencies of U. N. O. describes the economic situation and broad economic trends obtaining in these countries during 1950. It reviews important aspects of the economy of the region and contains a good deal of valuable statistical data. It has

been appropriately divided into two parts. The first part deals with the more general basic factors of development and includes chapters on economic resources, national income and economic development problems and trends. The second part reviews the developments of the year in the spheres of agricultural and industrial production, transport, international trade and payments, money and finance, including the problems of emerging new inflationary pressures in the Region. Both parts together contain 16 Chapters and 144 Statistical Tables and have a useful index at the end.

The Book is valuable for understanding the economic problems of the Region. In view of the importance of the new forces of political, social and economic development, which are now operating in the Region, and the important position which it holds as a supplier of several vital raw materials in the world economy, the survey is also not without significance for the world at large.

One interesting fact brought out by the survey is that planning of economic development is gaining prominence throughout the Region. The possibility of a speedy development, however, largely depends on the availability of adequate financial and technological assistance from the advanced countries of the West and the U. N. O. Agencies Although foreign help has increased in recent years, the total amount of aid so far given is small in relation to the needs of the Region. (S.R.S.)

REPORT OF THE UNITED NATIONS MISSION OF TECHNICAL ASSISTANCE TO BOLIVIA

(*Published by United Nations Publications, 1951. Price $1.5, pp. 128*)

AT the request of the Bolivian Government a Mission, comprising of 22 persons including administrative staff, was organised in 1950 to aid the Government of Bolivia in drawing up a programme of economic and social development. A brief account of political, social and economic situation of Bolivia, as reported by the Mission, is given below.

General. Bolivia has a population of about 4 million. The birth and death rates are 45 and 30 per thousand respectively and the population is expected to be double in about 24 years. It is a poor country inspite of its rich natural resources and this has been attributed to its economic and political instability. There have been 7 presidents and 8 revolutions in the last 10 years, 18 Ministries of Labour in 4 years and 8 Ministers of Finance within 18 months. National budget in 1950 was 27·83 million dollars. Foreign and domestic debts are 143 million and 24 million dollars respectively. Inflation due to unbalanced budget is very high and the cost of living index in 1950 was 850 against 100 in 1937.

Mining. Bolivia is a highly mineralised country but costs of mining are high because most of the minerals are in almost inaccessible mountain regions, sometimes at altitudes of 12,000 to 17,000 ft. Tin mining is most impottant and Bolivia produces about 20 per cent of world's tin production. In addition Lead, Silver, Antimony, Zinc, Tungsten, Copper, Gold, Bismuth are also mined. The export of mineral

products having a net value of 83 million dollars, represents 95 per cent of total Bolivian export and is virtually the only source of foreign exchange.

Agriculture. Bolivia has a total land area of about 4 lakh sq. miles, of which 2 per cent is in cultivation, though 70 per cent of total population depend on agriculture. Bolivia imports food stuffs worth 10 million dollars a year.

Forestry. Forested land in Bolivia covers nearly 40 per cent of the Republic area. There are 2,000 species of trees, including fine cabinet woods, rubber, etc., but there is lack of soft wood like pines and firs.

Transport. The land transport system consists of 2,500 kilometres of railroad and 36,000 kilometres of road. There are also air transport and inland waterways.

Power. There is no substantial deposit of coal in Bolivia. Water power and to some extent petroleum and timber are utilized for power generation. The total installed capacity of electric power is about 73,000 kw.

Industry. The chief manufacturing industries in Bolivia are textile, wheat flour and beer. Minor industries include cement, cigarettes, glass, shoe factories, saw mill, oil mill, aluminium plant, etc., 10·5 per cent of National income is derived from manufacturing industry, total capital investment being 20 million dollars and number of workers employed 20,000.

The mission has discussed at length the various problems of the country, viz., political stability, administrative organization, monetory, fiscal and budget policy, land tenure system, commercial, industrial and foreign policy, nutrition, housing, social evils, condition of labour, etc.

The main recommendations of the Mission are :

1. Government should keep expenditures for military, diplomatic and other services to a minimum ;
2. For improving the administrative efficiency of the country, the United Nations should recruit a number of experienced administrative officers for work in Bolivia on a temporary basis ;
3. There should be established a National economic administration, comprising of Ministers and top ranking officials to advise upon the major policies in economic, administrative and fiscal fields ;
4. For stimulating the growth of national income, no single factor is considered more vital than that of saving and it is proposed to establish a Bolivian Bank of economic development, with technical assistance from the International Bank for Reconstruction and Development. The chief functions of this bank will be to raise capital funds, establish necessary credit relations, promulgate a foreign investment code for inspiring the confidence of foreign investors, create a net work of savings bank and strengthen commercial and mortgage banks ;
5. There should be further expansion of mining, industry, agriculture and utilization of forest resources ; with provision for enlarged and improved facilities for higher technical education, transport, irrigation, soil

treatment, etc., to meet the increased Power requirement, a Bolivian Power Corporation should be established for development of dams and petroleum industry ;

6. Steps should be taken for improving the conditions of labour and social welfare organizations like orphan asylums, child welfare, etc. ;
7. Order of priority to be followed in implementing the economic proposals should consist of three stages. In the first period there should be heavy imports of capital for development of mining, industry and agriculture. In the second period, there should be gradual tapering off of foreign investment and for saving of foreign exchange there should be developed agriculture, forestry and industries based on agricultural raw materials like sugar and oil mills, textile factory, etc. In the third period there should be cessation of capital imports and foreign assistance ;
8. For implementation of the Mission's recommendations, negotiation of a firm agreement of treaty between the Bolivian Government and the United Nations is suggested, whereby the United Nations can assist the Bolivian Government in the appointment of administrative assistants, providing technical assistance, establishment of the National Council on Public Service and other matters.

The Mission has spent considerable time and energy in preparing this plan, which has been very well drawn. For implementation of the proposals, proper leadership and determination of the people of Bolivia are absolutely essential, in addition to assistance from the United Nations. There is no doubt that by execution of the plan, tremendous social and economic progress will be derived in Bolivia within the next few years. (J.C.G. and S.K.N.)

THE CYST-FORMING SPECIES OF HETERODERA

By Mary T. Franklin, Ph.D.

(*Published by Commonwealth Agricultural Bureau, Farnham Royal, Bucks, England, pp. 147+4 with 21 figures (including 8 photographs) and 646 references, price 18 shillings and 6 pence net*)

THIS small book is a technical communication of the Commonwealth Bureau of Agricultural Parasitology (Helminthology), St. Albans, England. As the title indicates this contribution compiles most of the work published upto 1948 on the cyst-forming species of the genus *Heterodera*, the root-knot eelworm (*H. marioni*) being mentioned only in a general way. Out of about a dozen fully or partly recognized species of the genus, the following eight have been described in detail in separate chapters : (1) *H. schachtii* Schmidt 1871 and its varieties and races (two chapters), (2) *H. cacti* Filipjev and Schuurmans Stekhoven, 1941, (3) *H. major* [O. Schmidt, 1930] ; (4) *H. gottingiana* Liebscher 1892, (5) *H. cruciferae* Franklin 1945, (6) *H.*

humili Filipjev 1934, (7) *H. punctata* Thorne 1928, and (8) *H. rostochiensis* Wollenweber 1923. For each of these species all the available informations have been brought together on their morphology, bionomics, distribution and hosts. The effect on host has also been discussed in detail for all the species except *H. cacti*. Methods of control have been indicated for each species except the one mentioned above. These methods have been dealt with in detail in the case of *H. schachtii* and *H. rostochiensis*. All the available information on chemical, biological, ecological and legislative controls has been brought together for the control of these two species. The contribution will certainly be most welcome to all the workers on applied nematology and specially to those in the agricultural departments who have to control these pests in the field. (E.S.N.)

THE GRASS CROP

By William Devies

(Published by E. & F. N. Spon, Ltd., London, 1952, pp. xiii-318, price 26/-)

The very title ' Grass Crop ' indicates the importance of the book. There was a time when grass was not considered a crop nor was its importance recognized. But today grass and its asscoiated herbage the legume rank equal in importance to several cereal and millet crops in the national economy of many of the Western countries. Grassland workers all over the world look forward with much interest to the arrival of a new book on grass to get fresh ideas and Mr. Devies's book is therefore a welcome addition. William Devies has made the study of grass in all its aspects, his major interest in life and 30 years of valuable experience gathered by him find expression in this work.

The book deals with all aspects of grass production from reclaiming untamed forests to grass to the production of best pastures. The consideration of the subject is based on the inter-relationship that exists between the soil, the animal and the herbage, a fact that has not yet been adequately recognized. As it happens too often much attention is paid to one or other of these three factors to the detriment of the remaining. Devies has pointed out the necessity for paying equal attention to all the three aspects. His chapter on ' Introspect ' is, therefore, the most important and instructive. He draws attention to the importance of an understanding of the ecology of grasslands as it helps in recognizing the limits to which grasslands could be ruined by mis-use of them. Although the book is devoted mainly to the consideration of grasslands of the temperate regions, it provides useful information to workers in the tropics and the sub-tropics as well.

Every aspect of the grassland viz., establishment, seed production, balancing the sward, correct management, etc., is discussed and sound advice based on practical experience or on factual data is given.

The interesting feature of the book is that a valuable and much needed post-script has been added on grassland research. Because it is research that stimulates improvement in general practice in any occupation. A warning, however, is given

not to rely wholly on new ideas based on few years of research so as to discard age-long practices born of experience. A careful blending of the two would lead to better results than by considering that a change for the new is always a change for the better.

The book 'Grass Crop' is well worth a careful study by grassland workers, professional graziers and those interested in livestock production and dairy development. (L.S.S.K.)

FLOOD DAMAGE AND FLOOD CONTROL ACTIVITIES IN ASIA AND THE FAR EAST

PREPARED BY BUREAU OF FLOOD CONTROL

(Published by United Nations Economic Commission, November 1951, pp. 82, price \$ 1·50)

THIS Book was published by the Bureau of Flood Control, United Nations Economic Commission for Asia and the Far East in November 1951. A reviewer in 1952 naturally finds that the information given in the book is not always up-to-date.

In the first part of the book a brief study of the general characteristics and pattern of basic climatological and hydrologic, elements such as Temperature, Pressure and Wind, Precipitation and Cyclones, Runoff, Siltation and Erosion which are directly related to the Problem of Floods and Flood Control, has been given. A critical examination of the significant factors and their implications in the problem of Floods and Control have been made briefly for clearer representation of the nature of the problem to be encountered in reality and for intelligent and successful solution by suitable engineering methods.

The second chapter is devoted in general to the Development of Flood Control Works in the region AFE. The history of man's continuous encroachment on rich alluvium of river valleys and deltas for agriculture, the consequent crippling of rivers, and the mis-use of land by extensive deforestation, have been presented in detail. The means which were gradually developed to protect crop, land and life from ravages of flood have been shown to be always influenced by either Population Pressure or by Physiographical features of the river basins. The construction of levee or dike as a control measure against floods has been favoured in densely populated river valleys and deltas. Flood control measures other than the popular type of levees and dikes have been due to the influence of physiographical features demanding different types of solution. The various means which have been evolved and applied as control measures against floods commencing from the early construction of a single levee or dike for individual interest to the workings of modern projects of multipurpose unified river basin development for the benefit of all have been summarized towards the end.

The last chapter deals with Flood Damage and Flood Control Activities of the various rivers of the ECAFE region. 20 major river basins have been studied separately. These are Brahmaputra, Ganges, Kosi, Damodar and Mahanadi of India, Indus of Pakistan and of India, Kelani Ganga of Ceylon, Irrawaddy of Burma, Chao Phya of Thailand, Mekong of Cambodia and South Viet Nam, Solo and Brantas of Java, Agne and Pampanga of Philippines, and Red, Pearl, Yangtze, Yellow, Huai and Hai of China. Studies of each river basin have been made under 4 different sections. In the first section, the physical description of the river system, basin characteristics with size and shape, soil conditions and erosional state, and hydrometeorological features have been given. In the 2nd section, a study of Flood and Flood Damage has been made. A history of all major known floods, magnitude and duration of flood discharges and a statistical analysis of flood frequency have been presented. An estimate of the extent of damages done by some recent floods in the various river basins has been given, from which the average annual loss due to flood damages to crop, lands, buildings and utilities has been computed. The 3rd section deals with the Flood Problem and the proposed Plan of Flood Control. An account of the cause and nature of the floods to be expected in the basin and the plan which is being proposed for the flood control have been given in brief. In the last section, some details of the Flood Control Activities which are either in progress or are completed and the names of the various governmental agencies or organizations which are mainly responsible for looking after the successful workings of the projects have been given.

Exhaustive treatment of Flood Control Problem and critical appreciation of the various methods or detailed evaluation of the tangible and intangible flood damages are not intended to be covered in the book. However the book contains fair amount of factual data on floods and flood control and gives a clear picture of the extent of damages done by the floods in the various river basins. Above all, it highlights the river basin developments which are necessary to conserve food and land in this area. (J.C.G. and S.K.G.)

MGIPC—M—27 AR—9-5-53—780.

Publications Committee

The Editorial Board, in its work of examining papers received for publication, is assisted in an honorary capacity by a large number of scientists working in various parts of India.

Editorial communications including books and periodicals for review should be addressed to the Secretary, Indian Council of Agricultural Research, Publication Section, New Delhi.

Communications regarding subscription and advertisements should be addressed to the Manager of Publications, Civil Lines, Delhi.

Instruction to Authors

Articles intended for *The Indian Journal of Agricultural Science*, should be accompanied by short popular abstracts of about 330 words each.

In the case of botanical and zoological names the International Rules of Botanical Nomenclature and the International Rules of Zoological Nomenclature should be followed.

Reference to literature, arranged alphabetically according to authors' names, should be placed at the end of the article, the various references to each author being arranged chronologically. Each reference should contain the name of the author (with initials), the year of publication, title of the article, the abbreviated title of the publication, volume and page. In the text, the reference should be indicated by the author's name, followed by the year of publication enclosed in brackets; when the author's name occurs in the text, the year of publication only need be given in brackets. If the reference is made to several articles published by one author in a single year these should be numbered in sequence and the number quoted after year both in the text and the collected references.

If a paper has not been seen in original it is safe to state 'original not seen.' Sources of information should be specifically acknowledged.

As the *format* of the journal has been standardized, the size adopted being crown quarto (about $7\frac{1}{4}$ in. $\times$ $9\frac{5}{8}$ in. cut), no text figure, when printed should exceed $4\frac{1}{2}$ in. $\times$ 5 in. Figures for plates should be so planned as to fill a crown quarto page, the maximum space available for figures being $5\frac{1}{2}$ in. $\times$ 8 in. exclusive of that for letter press printing.

Copies of detailed instructions can be had from the Secretary, Indian Council of Agricultural Research, New Delhi.

Editorial Board